Wagenhals, Gerhard

Working Paper

The impact of copper production from manganese nodules: A simulation study

Kiel Working Papers, No. 192

Provided in cooperation with:
Institut für Weltwirtschaft (IfW)

Kieler Arbeitspapiere
Kiel Working Papers

Kiel Working Paper No. 192*

THE IMPACT OF COPPER PRODUCTION FROM MANGANESE NODULES

A Simulation Study

by

Gerhard Wagenhals

December 1983

Institut für Weltwirtschaft an der Universität Kiel

ISSN 0342-0787

Institut für Weltwirtschaft Kiel
Forschungsabteilung I
Düsternbrooker Weg 120,
2300 Kiel /Federal Republic of Germany

Kiel Working Paper No. 192*

THE IMPACT OF COPPER PRODUCTION FROM MANGANESE NODULES

A Simulation Study

by

Gerhard Wagenhals

December 1983

* This paper is part of a research project on ocean use and policy; financial support has been provided by the Deutsche Forschungsgemeinschaft (Sonderforschungsbereich 86 / Teilprojekt 1, Allokations- und Verteilungsaspekte der Meeresnutzung). I would like to thank Federico Foders for helpful comments.

ISSN 0342 - 0787

ABSTRACT

The first part of the paper describes the main features of the world copper industry, including consumption, inventories, prices, trade, primary and secondary supply as well as reserves and resources. In the second part an econometric model of the world copper market is derived; theoretical and empirical justifications are provided for some representative equations. Finally, the third part of the paper deals with the results of forecasting and simulation experiments performed with this model. A conditional forecast of the major future developments in the world copper industry and an assessment of the likely impact of ocean floor mining on the copper market constitute the main topics discussed in this part. Base case simulation results (without seabed mining) are reported and compared to three alternative scenarios assuming different recovery rates for copper from deep sea manganese nodules.

List of Tables

List of Figures

List of Equations

I MAJOR FEATURES OF THE WORLD COPPER MARKET

The first part of this paper provides background information on the world copper market as far as it is necessary to understand the econometric model of the world copper industry, developed in the second part of this report. It describes the historical pattern and major determinants of world copper demand, supply and price formation, and discusses the development of foreign trade and future copper availability[1].

1. Consumption Pattern

1.1 End-Uses

Copper, the red metal, is a very versatile raw material characterized by its high electric and heat conductivity, malleability, corrosion resistance, tensile strength and easy workability. These properties make it useful in a battery of applications in many sectors of the economy as an intermediate product, but in a few fields also as a final product, especially in the arts, due to the metal's pleasant reddish color.

Typically, the refined metal is consumed by wire rod mills, brass mills, ingot makers, foundries, powder plants and other industries. Then, the supply of wire and brass mills, foundry and powder products is consumed in end-use markets, which utilize copper e. g. in form of bare wires, insulated wires and cables, strips, plumbing tubes, rods and bars, castings (sand, die, permanent mold etc.) and powders.

---

[1] Many important topics have to be neglected in this short introduction. For more complete surveys on the world copper industry see e. g. Gluschke, Shaw, Varon [1979], Mikesell [1979] or Wagenhals [1983a].

The most important end-use markets are:

- building construction (e. g. plumbing and heating, building wiring, builders' hardware and architectural uses),
- electrical and electronic products (e. g. telecommunications, power utilities, lighting and wiring devices),
- industrial machinery and equipment (e. g. industrial valves and fittings, heat exchangers),
- transportation equipment (e. g. autos, trucks and buses, aircraft and aerospace),
- consumer and general products (e. g. appliances, fasteners and closures, ordnance, coinage, utensils and cutlery).

These end-uses are typical for the consumption of refined copper in the major industrialized countries. As an example, Table 1 presents consumption shares by end-uses in the United States, the respective shares in other industrialized countries being similar.

Table 1 - Supply of Mill Products to US Markets, 1960, 1970, 1980, 1982, in per cent[a]

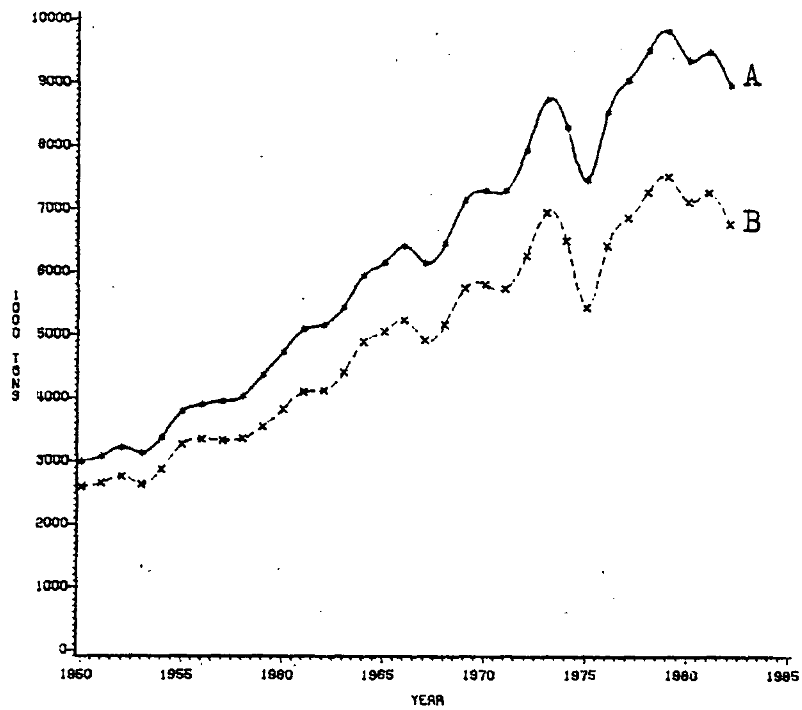
	1960	1970	1980	1982
Building construction	22	29	31	31
Electrical and electronic products	28	28	28	29
Industrial machinery and equipment	21	21	19	18
Transportation equipment	13	10	10	10
Consumer and general products	16	13	13	13
Total	100	101	101	101

[a] The figures do not sum up to 100 due to rounding.

Source: Calculated from Copper Development Association, Copper Annual Data, various issues.

Since the Second World War, world consumption of refined copper grew rather steadily, with the exception of the recession years in the mid 1970s and in the early 1980s, and with a slightly flagging demand in 1967, when the longest and costliest strike in history affected the US copper industry. Figure 1 shows the development of refined copper consumption in the postwar period, both for the world and for the market economies.

Figure 1 - Refined Copper Consumption, Total World (A) and Market Economies (B), 1950 - 1982, in 1 000 tons



Copper consumption is concentrated in the main industrialized countries of the "North". Since the last few years, some newly industrializing economies, natably Brazil and South Korea, account for a small, but increasing share of the world's total refined copper consumption.

In the last three decades, the United States' and the United Kingdom's consumption shares declined considerably, whereas most other major consumers' shares did not change significantly. However, Japan's proportion grew about sixfold in this period. Tables 2 and 3 show growth rates and consumption shares for the most important copper users. The picture for the use of copper in all forms, including the direct use of copper and copper alloy scrap by manufactures, looks quite similar and is therefore not depicted here[1].

Table 2 - Growth Rates in Refined Copper Consumption by Countries, in per cent

Country	Average annual growth rates				
	1950-60	1960-70	1970-80	1980-82	1950-82
United States	-0.8	4.1	0.0	-5.8	0.7
Soviet Union	7.7	3.9	3.2	0.0	4.6
Japan	17.5	10.4	3.5	3.6	9.9
Germany, F. R.	11.0	3.1	0.7	-1.1	4.4
France	7.3	3.4	2.7	-1.7	4.1
United Kingdom	5.1	-0.1	-3.0	-6.8	0.1
Italy	8.6	4.0	3.5	-6.1	4.6
Market economies	4.0	4.3	2.1	-2.6	3.0
Total world	4.7	4.4	2.6	-3.0	3.4

Source: World Bureau of Metal Statistics and own estimates.

Besides the countries listed above, other important consumers of refined copper include Australia, Belgium, Canada, the People's Republic of China, East Germany, Poland, Spain, Sweden and Yugoslavia, which respectively accounted for between

1 See e. g. Wagenhals [1983a, pp. 37 - 38].

one and four per cent of the world's refined copper consumption in the early 1980s. The amount of refined copper used in the four most important copper exporting developing countries reached less than one per cent[1].

Table 3 - Country-Shares in World Consumption of Refined Copper, in per cent

Country	1960	1970	1980	1981	1982
United States	25.9	25.5	20.0	21.4	18.5
Soviet Union	13.8	13.0	13.9	13.9	14.5
Japan	6.4	11.3	12.4	13.2	13.9
Germany, F. R.	10.9	9.6	8.0	7.9	8.2
France	5.0	4.5	4.6	4.5	4.7
United Kingdom	11.8	7.6	4.4	3.5	4.0
Italy	3.9	3.8	4.1	3.9	3.8
Sum	77.7	75.3	67.4	68.3	67.6

Source: Calculated from World Metal Statistics.

1.2 Substitutes and Complements

Substitutes

Aluminum, plastics, stainless steel, and fiber optics may substitute for copper in certain applications, as well as other non-ferrous metals, like, for instance, lead, zinc, and titanium[2].

---

[1] For more information on copper consumption see Wagenhals [1983a, Chapter 3].

[2] See Wagenhals [1983a, pp. 38 - 47] for more details.

Copper's most important substitute is aluminum, a metal, which is lighter than copper. In spite of copper's superior electrical conductivity, there is an edge for aluminum in terms of capacity per unit of weight. This property has led to substitution in the electrical industry, especially in electrical conductor applications. Aluminum coaxial cables have completely displaced copper cables in high voltage transmission. In low and medium voltage transmission, copper sustained losses in the fabrication of underground cables. Heat exchanger applications is another field, where aluminum is increasingly used instead of copper.

Stainless steels are also significant competitors of copper, especially when high resistance to corrosion, hardness, heat-resistance, ductility and tensile strength are important. Titanium is similar to stainless steels in many properties, and it is considerably lighter. Its very high price compared to copper usually excludes it as a substitute in common applications, at least for the time being[1].

In some chemical applications, lead and zinc may be used as copper substitutes. Coinage could also be a future field for zinc. In construction, lead may be used instead of copper for plumbing, but, especially in tubing and pipes, plastic materials become increasingly important in plumbing drains. In coldwater plumbing systems, for example, polyvinyl chloride has often replaced copper. Eventually, in the near future, fiber optics instead of the red metal may play an important role in telecommunications.

1 Goeller and Weinberg [1978] present interesting views on potential long range copper substitutes.

In spite of many substitution processes which have tended to reduce the demand for the red metal, many possible new uses of copper can be envisaged. In less developed countries, electrification will increase copper demand, in industrialized countries, the production of more energy-efficient motors necessitates extra copper windings. Solar energy and water desalination open new application fields for copper in construction, and electrically powered vahicles could increasingly require copper in the transportation industry. In less developed economies, the market of copper-bearing consumer goods, like household appliances, certainly has a significant growth potential.

Complements

Copper is often used in alloys, and naturally its alloying elements are the most important complements of the red metal.

Brass is the most important copper alloy. In the first three months of 1983, brass mills used almost 40 per cent of the total refined copper in the United States[1]. Because brass contains some 10 - 60 per cent zinc, this metal is an important complement in copper consumption. In bronze, an alloy basically of copper and tin, these two metals also are complements.

1.3 Determinants of Consumption

Important factors determining the level and composition of copper consumption are own prices of substitutes, mainly of aluminum, after suitable deflation. Copper and copper-alloys are usually only relatively minor inputs in down-stream

[1] Calculated from World Metal Statistics, July 1983, p. 64.

industries, for instance in the electrical and electronic products industries and in building construction, but also in the transportation, industrial machinery and consumer goods industries. Therefore, usually the level of economic activity, either of an end-use sector or of the economy in general, influences copper consumption together with relative prices. Other possible determinants of copper usage include the expected future availability of the metal and its substitutes, and the volatility of the respective markets.

Like many raw materials, copper is characterized by low short-run, and high long-run price elasticities of demand. Although the estimation of elasticity figures may be seriously criticized[1], some results for the copper consumption of the world's major copper users are presented. It is important to stress that the own price elasticities should be interpreted as lower bounds, since we do not assume distributed lags on the price of aluminum. In regression experiments not discussed here, where distributed polynomial lags were stipulated, the t-statistics were lower for both prices. We assume that a lower bound of elasticities, which is statistically sound, is superior to an inaccurate estimate, which may be closer to the value expected a priori. The following table shows the elasticities of demand for copper consumption in all forms calculated by the author, based on data from 1955 to 1980 for some of the most important copper users[2].

---

[1] See e. g. Hojman [1980].

[2] See Part II of this report for a description of the assumptions underlying the estimates. We also obtained price elasticities of demand for Brazil and France, but they were not significantly different from zero and had the wrong sign. The respective demand elasticities with respect to industrial production were highly significant, however.

Table 4 - Copper Demand Elasticities

Country	Elasticity with respect to ... own price	aluminum price	industrial production
Germany, F. R.	-.0814	.278	.748
Italy	-.0760	.140	.892
Japan	-.0972	.305	.826
United States	-.0346	.129	.461
Other market economies	-.0851	.129	.912

2. Inventories, Prices and Trade

2.1 Inventories

Copper inventories serve as buffers between copper production and consumption. Stocks of unwrought copper are held in the form of blister and anode copper at producers; refined copper is stored at metal exchange stocks (the London Metal Exchange and the New York Commodity Exchange) as well as at producers, merchants and at consumers in producing and consuming countries.

Apart from these private inventories, copper is also stored officially. Currently only in the United States a strategic stockpile exists. Although the stockpile goal of the US government currently amounts to 907 000 tons, the stockpile actually contains only some 20 000 tons. In 1976, the Japanese government started a stockpile program, which has been discountinued in 1982. The Japanese industry established a copper buffer stock financed by private funds and assisted by governmental interest subsidies. The French and West German governments have also considered the possibility of official stockpiling, but no decision has been reached up to now. Extensive discussions about international public copper stockpiles in the context of UNCTAD's "Integrated Programme for Commodities" has not reached an agreement on institutional arrangements to stabilize copper prices.

In 1982: 1.5 million tons of unwrought copper were stored commercially in the market economies, and only some 20 000 in governmental stockpiles. In the early 1950s, the relation between private and official inventories was inverse: in 1950, the US strategic stockpile amounted to 482 300 tons, compared to 121 000 tons of total commercial stocks[1]. Figure 2 shows the development of private stocks, of official stocks, and of the sum of private and official stocks since 1950. Although a substitution of private for public stocks can be ascertained in the last three decades[2], the US stockpile authority managed the reduction of the huge governmental copper stocks remarkably well without major disturbances of the market allocation[3].

2.2 Price Formation

The majoritiy of concentrates, blister and refined copper in the market economies is sold on bilateral annual contracts between producers and consumers, i. e. usually between refineries and semi-fabricators. The rest, some 10 - 20 %, is sold through two exchanges, the London Metal Exchange (LME) and the New York Commodity Exchange (COMEX), where a free market price for a few types of refined copper is established, and where future markets allow hedging and speculation.

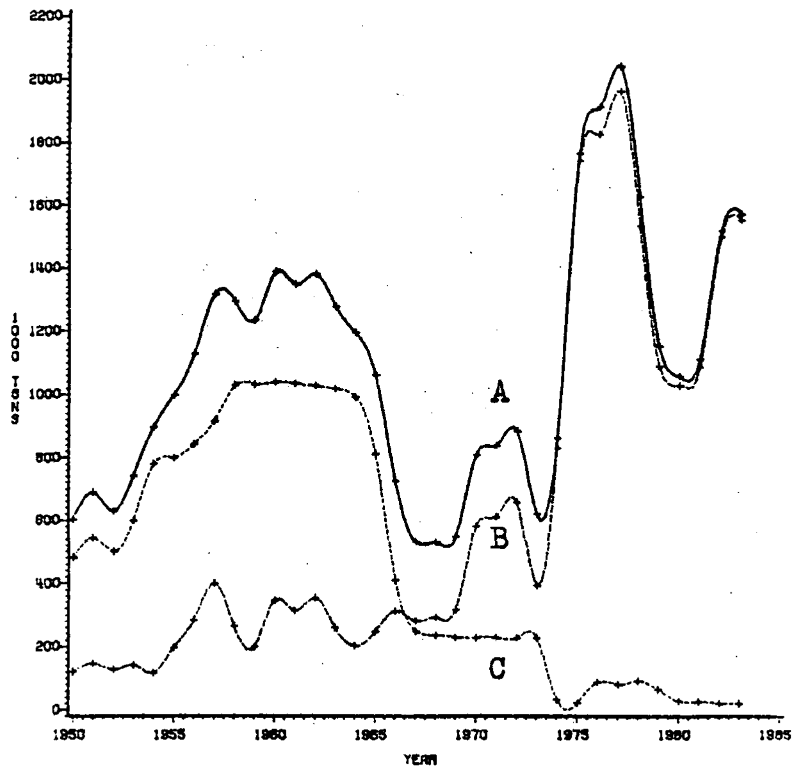
---

1 Source: World Metal Statistics.

2 See Wagenhals [1981].

3 Incidentally, it may be Interesting to know that the US General Services Administration used econometric copper market models, e. g. Behrmann [1970], to perform this task.

Figure 2 - Development of Private (B), Official (C) and Total (A) Refined Copper Stocks, 1950 - 1982

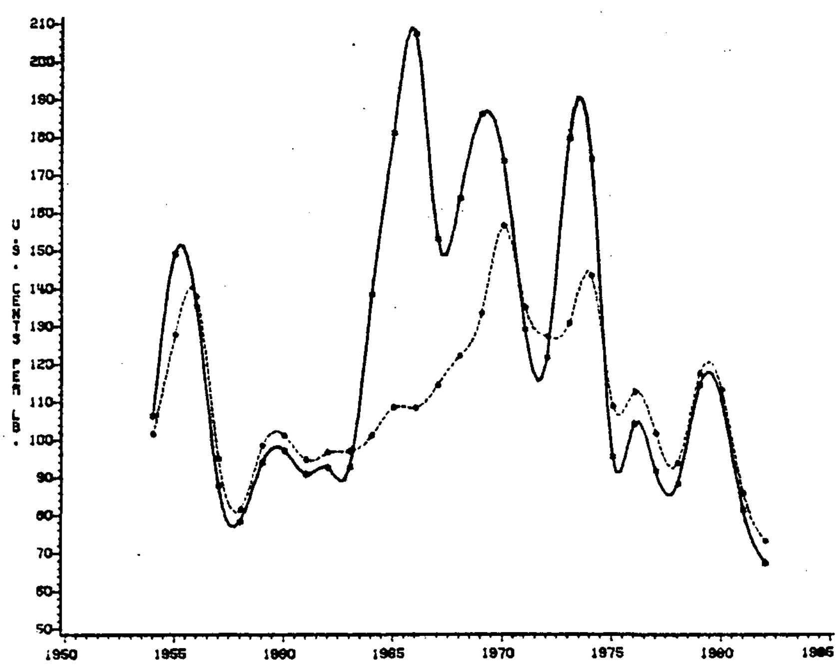


The price of refined copper traded outside North America is generally based on an average of copper price quotations at the LME. The prices of concentrates and blister copper allow for smelting and refining charges, but they also depend strongly on LME prices.

In North America a producer pricing system exists. Until the late 1970s, the main copper producers fixed prices unilaterally, changing them only infrequently. Because of increasing international competitive pressures, in early 1978 the major producers switched to exchange-based pricing. Currently, they determine their prices in line with the copper quotations at the New York Commodity Exchange, whose prices are highly correlated with the corresponding LME quotations due to arbitrage transactions.

Figure 3 shows the development of the US producer price and the LME price (in 1982 constant US $ per lb) from 1950 to 1982[1]. The figure indicates the high volatility of the LME price compared to the US price. To avoid long-run substitution away from copper, the major vertically integrated producers in the United States sometimes rationed their consumers and stabilized prices. These periods of the so-called two-tier price system[2], when US and world market prices differed significantly, show up clearly. The figure shows also that in recent years, when competition among colluding oligopolistic copper producers in North America increased, the US producer prices more and more approximated the free market quotations.

Figure 3 - US Producer Price and LME Price, Electrolytic Copper, Wirebars, Constant 1982 US $ per lb, Cubic Spline Interpolation



[1] Calculated from Metallgesellschaft AG's Metal Statistics. Deflator is the producer price index published by the US Bureau of Labor.

[2] See McNicol [1975] for a description of the two-tier price system.

Figure 3 indicates substantial fluctuations in real copper prices, especially for the free market price formed at the London Metal Exchange. However, a statistical analysis shows, that no time trend in real copper prices can be ascertained, neither in the post war period[1], nor in the very long-run[2].

2.3 Foreign Tade

Copper is mainly traded in refined form, but due to relatively low ocean freight rates in relation to the price of copper, trade in concentrates and blister is also significant.

The main trade flows originate in a few countries, namely in the developing economies of Chile, Zambia, Zaire and Peru, but also in inudstrialized Canada, and they end in Japan and the European market economies. Some trade also takes place between the United States and the rest of the market economies, as well as between East and West in general, especially between Poland and the Federal Republic of Germany.

On average, from 1970 to 1980: 59 % of the total world exports were traded in refined form, 23 % as concentrates and 18 % as blister copper[3]. In 1982 copper exports in all forms (excluding copper and copper alloay semi-manufactures) amounted to almost 5 million tons, 55 % of which were traded in refined form, 30 % as concentrates and 15 % as blister and anode copper. In the last twenty years, new pits went onstream in some developing countries without smelting facilities (e. g. in Indonesia or Papua New Guinea) and the

---

[1] See Wagenhals [1983a, pp. 93 - 95].

[2] Cf. e. g. Radetzki [1977].

[3] See Wagenhals [1983a, pp. 49 - 54] for a detailed description of foreign trade in the world copper industry.

domestic refining capacities of other developing economies increased (e. g. in Peru and Zambia), leading to an increasing share of concentrates and refined copper exports.

Tables 5 and 6 list the major exporters and importers of copper concentrates, blister copper and refined copper in 1982.

Table 5 - Copper exports of Main Producers, 1982

Country	Conc.	Blister '000 tons	Refined	Conc.	Blister per cent	Refined
Chile	200.9	199.8	807.4	13.4	27.0	29.6
Indonesia	76.9	-	-	5.1	-	-
Mexico	132.0	-	-	8.8	1.3	-
Papua New Guinea	173.3	-		11.5	-	-
Peru	38.2	97.0	208.5	2.6	13.1	7.6
Philippines	280.0	-	-	18.6	-	-
South Africa	-	77.8	70.1	-	10.5	2.6
United States	195.3	2.0	31.6	13.0	0.3	1.2
Zambia	-	-	602.6	-	-	22.1
Zaire	36.0	323.3	156.0	8.8	1.3	-
Total exports	1502.6	740.1	2726.1	100.0	100.0	100.0

Source: World Bureau of Metal Statistics, World Metal Statistics, July 1983.

Traditionally, copper trade between market and centrally-planned economies has been rather limited and has been restricted to trade in refined copper. Usually, the total net imports by Western countries do not exceed 2 % of their total copper use.

Table 6 - Copper Imports of Main Consumers, 1982

Country	Conc.	Blister '000 tons	Refined	Conc.	Blister per cent	Refined
Belgium	4.0	213.8	255.3	0.3	33.8	9.4
Brazil	-	-	204.7	-	-	7.5
France	-	22.5	367.9	-	3.6	13.5
Germany, F. R.	147.3	81.2	423.2	10.0	12.8	15.5
Italy	-	1.1	318.9	-	0.2	11.7
Japan	979.5	77.9	295.8	66.3	12.3	10.8
United Kingdom	-	68.1	255.5	-	10.8	9.4
United States	110.7	106.2	284.8	7.5	16.8	10.4
Total imports	1478.2	632.9	2726.9	100.0	100.0	100.0

Source: World Bureau of Metal Statistics, World Metal Statistics, July 1983.

The main links in East-Weat trade exist between Poland and the Federal Republic of Germany. From January to March 1983 almost three quarters of the market economies' imports from the East went to the Federal Republic of Germany, and 90 % of the total Western imports came from Poland. In the same period, more than three quarters of the total exports from Western countries of centrally planned economies originated in Peru, and almost 90 % of the market economies' exports were sold to the People's Republic of China[1].

[1] Prima facie it is surprising that, summing up, centrally planned economies import copper from Peru instead of importing it from Poland. The reason for this apparent paradox are transportation costs. Copper is shipped more cheaply from Peru to China than from Poland to China. Poland's foreign exchange needs in hard currency is a further determinant of copper exports to Western Europe.

Table 7 gives some evidence about East-West trade in refined copper after the Second World War. Until the early 1970s the Western countries generally were net exporters, but in the last few years they have become net importers.

Table 7 - East-West Trade in Refined Copper, in 1000 Tons

Year	Western imports	Western exports	Western net imports
1950	0.7	12.4	-11.0
1960	1.7	96.7	-95.0
1970	36.6	96.6	-60.0
1980	140.3	99.4	+40.9
1981	138.3	83.6	+54.7
1982	161.8	119.6	+42.2
1983 (Jan.-March)	29.3	37.3	-8.0

Source: World Bureau of Metal Statistics, World Metal Statistics, July 1983.

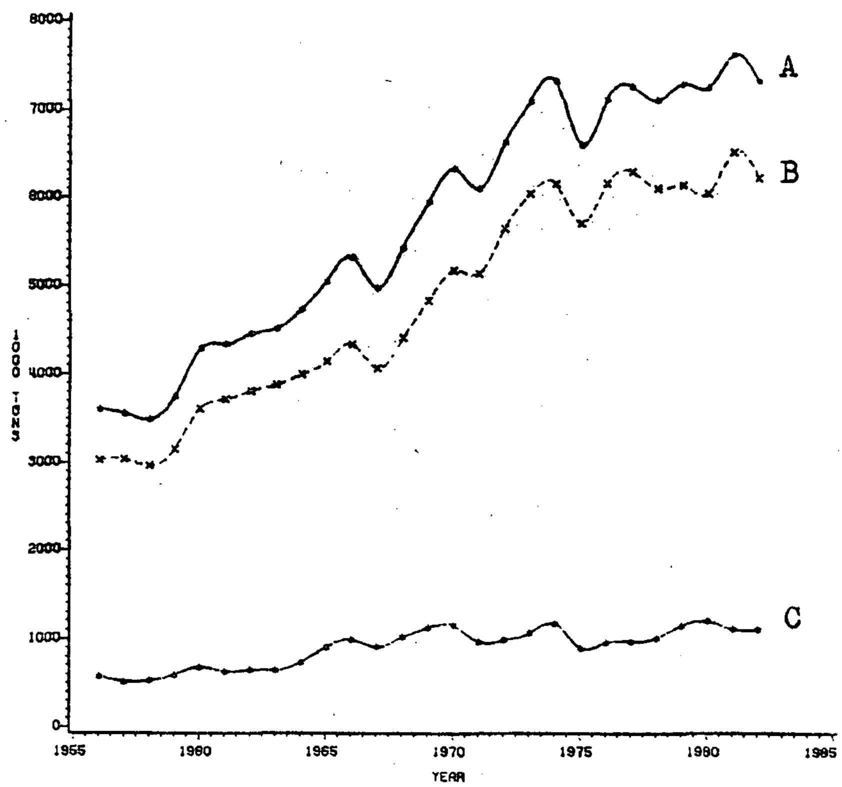
3. Supply, Reserves and Resources

3.1 Primary Supply

Primary copper is copper produced from newly mined ores and concentrates, secondary copper is derived from copper or copper alloy scrap.

Figure 4 shows the development of primary, secondary and total (i. e. primary plus secondary) copper production in the market economies since the mid 1950s. By and large, primary and secondary copper output increased in the last three decades. In comparison with refined consumption, the volatility of the supply side is more pronounced, because copper production is very highly susceptible to exogenous shocks, especially to strikes and transportation bottlenecks.

Figure 4 - Primary (B), Secondary (C) and Total (A) Copper Production, Market Economies, 1956 - 1982



Unlike many raw materials, copper is not predominantly mined in developing countries, but in considerable amounts also in industrialized countries. The latter accounted for some 50 % of the 8 million tons of copper mined in 1982. Main producers are the United States, Chile and the Soviet Union; Table 8 presents some data about the shares in copper mine production by countries.

In the early 1980s, between one and five per cent of the world mine output was respectively extracted in Australia, the People's Republic of China, Indonesia, Japan, Mexico, Papua New Guinea, Poland, the Philippines, the Republic of South Africa, and Yugoslavia. The European Community's output share amounted to less than one per cent.

Table 8 - Country-Shares in World Mine Production of Copper Ore (metal content) in per cent

Country	1950	1960	1970	1980	1982
United States	32.7	23.1	24.4	15.0	14.1
Soviet Union	8.6	11.8	14.4	14.4	14.0
Chile	14.4	12.6	10.8	13.6	15.4
Canada	9.5	9.4	9.5	9.1	7.7
Zambia	11.8	13.6	10.7	7.0	6.6
Zaire	7.0	7.1	6.0	6.0	6.2
Peru	1.2	4.3	3.4	4.7	4.4
Sum	85.2	81,9	79.2	69.8	68.4

Source: Compiled from various issues of Metal Statistics and World Metal Statistics.

Copper mine production depends on the prices of copper, and - at the level of a single mine - on the prices of its main by-products[1] (i. e. especially precious metals' prices, but also e. g. on the prices of cobalt, molybdenum, nickel and zinc). Available capacity, i. e. the maximum mill throughput per time unit, also strongly influences current production. In developing economies exogenous constraints (e. g. regarding foreign exchange reserves, transportation bottlenecks, or energy availability) may hamper adjustments to desired output levels, while industrialized countries increasingly tend to regulations aiming at the reduction of air and water pollution.

1 For a survey of the economics of copper's by-product metals see Petrick et al. [1973].

The following table presents the elasticities of copper mine supply derived from the estimated copper mine production equations estimated in the second part of this paper[1].

Table 9 - Short-Term Mine Production Elasticities of Major Copper Producers

Country	Elasticity with respect to ... capacity	price
Canada	0.89	0.23
Chile	1.14	0.07
Peru	1.15	0.17
Philippines	0.95	0.07
South Africa / Namibia	0.98	0.05
United States	0.87	0.20
Zaire	0.87	0.06
Zambia	0.91	0.10

The post-war history of the world copper industry is characterized by a considerable increase in competitiveness because of growing reserves and resources of the metal, widely spread all over the globe, due to an extensive diffusion of technology for the working of low-grade porphyry ore bodies, and also to rising operations of state-owned mining enterprises[2]. Although, historically seen, these factors too have influenced primary copper supply, they have not been included in our econometric model explicitly because not enough data is available to assess their relative impacts and to incorporate them in a formal way.

1 The coefficients are subject to the same qualifications as the parameter estimates in the description of demand elasticities.

2 See United Nations [1981: 29 - 32] and Labys [1982].

3.2 Secondary Supply

Various grades of copper and copper alloy scrap exist, but the most common distinction is between old scrap, which comes from the scrapping of copper-containing used and worn materials, and new scrap, which arises from refuse in fabricating copper and copper alloy semi-manufactures in downstream industries.

While most old scrap has to be refined before its use, new scrap is frequently just remelted and used without additional refining. The production of copper from scrap and copper alloy scrap is concentrated almost totally in the industrialized countries. In 1982, for example, the developing economies accounted for less than 4 % of the Western World's total secondary refined copper production, which amounted to 1.1 million tons in 1982[1]. Table 10 presents the shares of the most important secondary copper producers in the period after the Second World War.

Table 10 - Country-Shares in Secondary Refined Copper Production of Market Economies, in per cent

Country	1950	1960	1970	1980	1982
United States	44.1	39.0	37.6	39.6	40.7
Germany, F. R.	23.8	19.4	17.5	15.5	16.7
Japan	9.6	9.0	8.9	10.4	10.8
United Kingdom	14.5	15.7	13.6	7.7	6.5
Belgium	n. a.	n. a.	6.2	5.7	5.5
Sum	n. a.	n. a.	83.8	78.9	80.2

Source: Calculated from World Bureau of Metal Statistics, World Metal Statistics, various issues.

---

[1] Source: World Metal Statistics, [July 1983].

Most scrap that arises is ingotted and used directly in the production of copper and copper alloy semi-manufactures, castings and chemicals. In 1982, for example, secondary refined copper accounted for less than a third of total scrap recovery. Manufacturers in the market economies used some 2.4 million tons of scrap directly in 1982, 37 % of that in Europe, 30 % in the United States, 20 % in Japan, and the rest in the developing economies[1].

Old scrap supply predominantly depends on scrap prices, as well as on the size, composition and life-span of available copper-bearing products. Naturally, the level of new scrap is determined by the same factors as total copper consumption, because new scrap is mainly process scrap in copper using activities.

3.3 Reserve Base and Resources

Copper bearing deposits are distributed widely all over the globe, onshore and offshore. The copper content of the earth's continental crust is about 70 parts per one million parts of rock. Ocean waters proper contain small amounts of copper, but they are neglegible in comparison to total copper resources in deep-sea nodules. Magmatic rocks (liquid-magmatic and hydrothermal deposits) and sedimentary deposits (including those of volcanic origin) contain above crustal averages of copper. Porphyry and sedimentary deposits are the most important onshore sources of copper, but some copper is also mined from magmatic-contact-metamorphic or metasomatic deposits.

Porphyry deposits occur predominantly in Latin America (notably in Chile, Peru, Panama and Mexico), in the United States, in Papua New Guinea and in the Philippines, while

---

1 Source: World Metal Statistics, [July 1983].

sedimentary and volcanic sedimentary deposits occur in Central Africa (especially in Zaire and Zambia), in Australia and Japan. Magmatic-contract-metamorphic and metasomatic deposits can be found in some Canadian provinces and in parts of the Soviet Union.

Offshore deposits of copper in polymetallic nodules, polymetallic incrustations and metalliferrous sediments and brines frequently occur in deep ocean basins, but they vary highly in regard to composition, grade and concentration[1]. In terms of copper content, nodule occurences in the Pacific Ocean are most promising. Here manganese nodules sometimes contain more than two per cent copper (by dry weight)[2]. Currently, commercial interest centers on the North Pacific ocean floor, especially on the so-called ore nodule belt bordered by the Clarion and Clipperton fracture zone east of Hawaii. Apart from the polymetallic occurences, in some regions, e. g. in Hudson Bay, offshore copper-bearing placers can be found[3].

In appraising copper reserves and resources, we follow the principles of classification published by the US Geological Survey and the US Bureau of Mines[4]. in 1982, the world's copper reserve base amounted to some 511 million tons[5], compared to 100 million tons in 1950[6]. This corresponds to an average annual growth rate of 5.2 %, compared with a 3.7 % annual growth rate of world copper mine output and with a 3.4 % annual growth rate of world refined copper consumption in the same period.

---

1 See Mikesell [1979, p. 350].

2 Amacher and Sweeny [1976, p. 298] quote this figure.

3 Mikesell [1979], ibid.

4 Copper resources include measured, indicated and inferred concentrations of the metal, reflecting various degrees of geological uncertainty. The reserve base consists of the in-place demonstrated resource (measured plus indicated). See Mineral Commodity Summaries [1981, pp. 184 - 197].

5 Source: Mineral Commodity Summaries [1983, p. 41].

6 See Tilton [1977, p. 10].

Table 11 presents the distribution of world copper reserves and resources (including and excluding offshore deposits)[1]. A comparison with extraction or consumption figures for the early 1980s demonstrates that current copper production can be sustained for a long time, even for a reserve base fixed at its current level[2].

In the post-war period, the concentration of the reserve base on countries decreased[3]. For example, the four most important developing copper-exporting countries' share declined from 44 % in 1970 to 38 % in 1982, probably mainly because of reduced exploration activities in these countries due to increasing political risks perceived by potential foreign investors[4].

In 1982, the world's total copper resources were almost five times greater than the reserve base, the land-based resources alone exceeded them more than three times[5]. Given these figures about potential future copper availability, it is no surprise that empirical evidence strongly suggests that no copper scarcity can be expected in the next few decades.

---

1 Figures of shares in total reserve base by countries/regions are calculated from Mineral Commodity Summaries [1983, p. 41], figures of shares in resources are calculated from Schroeder [1979].

2 Wagenhals [1983a, pp. 88 - 95] deals with the perspectives of copper availability more thoroughly.

3 See Wagenhals [1983a, p. 86].

4 Radetzki [1981] deals with this problem.

5 Calculated from Mineral Commodity Summaries [1983, p. 41].

Table 11 - Distribution of World Copper Reserve Base and Resources

Country/Region	Percentage share in ... reserve base	resources (land-based)	resources (total)
Canada	6.3	8.6	6.1
Chile	19.9	16.6	11.6
Peru	6.3	4.2	2.9
Soviet Union	7.0	n. a.	n. a.
United States	17.6	23.5	16.5
Zaire	5.9	3.1	2.2
Zambia	6.7	6.0	4.2
Market economies	88.3	85.7	60.2
Centrally planned economies	11.7	14.3	10.0
Offshore deposits	-	-	29.8

Source: Shares in total reserve base by countries/regions calculated from Mineral Commodity Summaries [1983, p. 41]. Shares in resources calculated from Schroeder [1979].

II AN ECONOMETRIC MODEL OF THE WORLD COPPER MARKET

1. Main Features of the Model

The second part of this report deals with the econometric model of the world copper market, which will be used in the third part to assess the impact of copper production from manganese nodules on land-based production. The model is a modified and updated version of the world copper market model presented in Wagenhals [1983a].

The model consists of some 60 structural equations describing the development of the world copper market. It is a system of interdependent, sometimes nonlinear simultaneous difference equations. The coefficients of the model were estimated with annual data from 1955 to 1980.

In comparison with other econometric copper market models[1], this model has some special features:

- with some 60 structural equations, it is the most highly disaggregated econometric copper market model currently available,
- primary supply functions are not derived from a partial adjustment approach, as in other econometric copper market models, but from factor demand and from restricted profit functions,
- copper mine production capacities are explained endogenously, they are derived from the hypothesis that producers act to maximize their discounted net cash flow,

---

[1] For a survey of econometric and other quantitative copper market models see Wagenhals [1983a, Chapter 6]. A broad survey of econometric minerals and metal market models in general is Wagenhals [1984a]. Adams [1973, 1975, 1980] has been pathbreaking in the econometric analysis of the impact of deep-sea nodule mining on the world copper market.

- a dynamic stock disequilibrium approach is used to determine the LME spot copper price,
- the LME copper future price is explained by the model,
- producer price equations are introduced not only for the United States, but also for Canada and Chile, and
- the modeling of behavior of private inventory holders uses a rational expectations approach.

The following sections describe our model in some more detail. They show, that our econometric description of the world copper market allows for many typical characteristics of the world copper industry, which have been described in the first part of the report. They also give some insight in the functioning of the model by sketching the underlying economic theory and by presenting some representative estimated demand, supply and price equations.

2. Demand Equations

It was stressed in the first part of this report, that copper is seldom used as a final product. Thus, the demand for the red metal is almost only derived demand. Because copper is easily storable, total demand can be partitioned in demand for current consumption and demand for storage.

2.1 Consumption

In deriving the consumption equations, we assume that a copper user's marginal profitability conditions are fulfilled and that his input requirement set is locally convex in a neighbourhood of the optimum. Then, the copper consumption function is a conditional factor demand function and thus depends on the relative prices of copper and its main substitution product (aluminum) and on an index of industrial activity as a proxy variable for the copper producer's output.

Therefore, the general form of a copper consumption function f is

$$Q^C = f(P,\ P^{AL},\ Y),$$

where Q^C = copper consumption,
P = deflated copper price in domestic currency,
P^{AL} = deflated aluminum price in domestic currency, and
Y = index for the copper user's output.

Economic theory does not suggest an a priori hypothesis concerning the choice of the functional form of f. Therefore a Box-Cox approach was chosen, which suggested a logarithmic format in all variables. Thus, the typical consumption equation reads

$$\log Q_t^C = \alpha_o + \alpha_1 \log P_{t-1} + \alpha_2 \log P_{t-1}^{AL} + \alpha_3 \log Y_t,$$

where the lagged adjustment of consumption to price changes is due to long-term contracts which are common in international copper trade.

Representative Equations

To the equation derived above a stochastic error term was added. Then, consumption equations of this format were estimated simultaneously with Zellner's method of seemingly unrelated regressions for total copper use in the Federal Republic of Germany, Italy, Japan, the United Kingdom, the United States, and for the rest of the market economies together. Dummy variables are avoided with only one exception: the extraordinary increase in the 1966 US copper consumption associated with the 1967/68 strike.

As typical estimation results, total copper consumption equations for Japan and for the Federal Republic of Germany are presented. Here and in the following, the figures in parentheses denote the t-statistics, and DW is the Durbin-Watson coefficient. If the parameters of the respective equations were estimated with the ordinary least squares method, then $\bar{R}^2$ is the adjusted coefficient of determination, if they were estimated with Zellner's method of seemingly unrelated regressions, no similar coefficient can be defined uniquely, and therefore no $\bar{R}^2$ is presented.

Equation 1:

Estimated Copper Consumption Equation, Japan

$$\log(QCJA) = \underset{(2.19)}{1.77} - \underset{(-2.49)}{.0972} \log((PCULME_{-1} \cdot REXJA_{-1}) / (REXUK_{-1} \cdot PWIJA)_{-1}) + \underset{(2.94)}{.305} \log((PALLME_{-1} \cdot REXJA_{-1}) / (REXUK_{-1} \cdot PWIJA_{-1})) + \underset{(48.0)}{.826} \log(IIPJA),$$

$$DW = 1.94,$$

where

QCJA	=	Total copper consumption, Japan, in 1000 tons,
PCULME	=	Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound sterling per ton,
REXJA	=	Exchange rate, Japanese Yen per US Dollar,
REXUK	=	Exchange rate, Pound sterling per US Dollar,
PWIJA	=	General wholesale price index, Japan, 1975 = 1.00,
PALLME	=	Average annual price of aluminum, 99.5 % ingot, London, Pound sterling per ton,
IIPA	=	Index of industrial production, Japan, 1975 = 100.

Equation 2:

Estimated Copper Consumption Equation, Federal Republic of Germany

$$\log(QCGE) = \underset{(7.35)}{2.71} - \underset{(-2.75)}{.0814} \log((PCULME_{-1} \cdot REXGE_{-1}) / (REXUK_{-1}$$

$$\cdot PWIGE)_{-1}) + \underset{(3.67)}{.278} \log((PALLME_{-1} \cdot REXGE_{-1})$$

$$/ (REXUK_{-1} \cdot PWIGE_{-1})) + \underset{(19.8)}{.784} \log((IIPGE),$$

$$DW = 1.80,$$

where

QCGE = Total copper consumption, Federal Republic of Germany, in 1000 tons,

REXGE = Exchange rate, Deutsche Mark per US Dollar,

PWIGE = Price index of industrial output, Federal Republic of Germany, 1975 = 1.00,

IIPGE = Index of industrial production, Federal Republic of Germany, 1975 = 100,

PCULME, REXUK and PALLME are defined above.

We sum up the most important results of copper consumption estimation:

- All variables in all copper consumption equations have the expected negative sign for own price elasticities, and they have

- the expected positive sign for cross-price elasticities;

- the elasticities of the deflated prices are always significantly different from zero, but they are small compared to the income elasticities, which are highly significant and have the sign expected a priori for all countries and regions.

Thus, the estimated equations indicate that the use of copper is influenced more by the general level of industrial activity than by prices. This is due to the fact that the copper input usually amounts to only a small fraction of the total materials' input in the copper using industries.

Refined Copper Consumption

The equations described above were estimated for total copper use, i. e. including the direct use of copper and copper alloy scrap. Refined copper consumption is assumed to be an affine function of total copper consumption.

For the refined copper consumption in the Federal Republic of Germany (QCRGE), for example, we obtain the following estimated equation:

$$\underset{}{QCRGE} = \underset{(-.652)}{-21.0} + \underset{(19.3)}{.826}\ QCGE, \qquad DW = 1.79$$

The respective equations for the other major copper consumers are very similar.

2.2 Demand for Storage

Basically, the demand for storage can be partitioned into demand due to transaction and demand due to speculative motives.

A speculator's realized profit is

$$\pi_t = I_t^s(P_{t+1} - P_t) - C(I_t^s),$$

where I_t^s is the amount of speculative stockholding (end-of-period stocks), and $C(I_t)$ denotes a differentiable cost function.

We assume that a speculator chooses end-of-period stocks to maximize the expected utility of profits:

$$\max E(U(\pi_t)),$$

where U is the speculator's nondecreasing, concave and at least twice differentiable utility function. We further assume that the conditional variance of prices is independent of the conditional expected value of the price in period t+1 (given the complete information set of period t). Then we derive the first order condition for the optimal amount of speculative storage. If the expected marginal revenue of the speculator exceeds his marginal costs, if he exhibits constant absolute risk aversion and if a few simplifying additional assumptions are fulfilled (Wagenhals [1983a, pp. 146 - 147]), then we can derive the following linear approximation to the optimal amount of speculative storage

$$I_t^s = \beta_o + \beta_1 \, \Delta p_{t+1}^e,$$

where β_o and β_1 are constants, and where Δp_{t+1}^e is the expected price change given the complete information set in period t.

We model the transaction demand for storage using the flexible accelerator hypothesis. According to this approach, desired end-of-period inventories depend linearly on output of the copper-using industries, and inventory holders do not adjust to the optimal inventory level immediately due to adjustment costs and delivery lags.

Naturally, inventory data does not allow for a partition of copper stocks according to the underlying motives of stockholding. Therefore, a hybrid approach had to be chosen to explain the actual amount of stockholding:

$$I_t = \gamma_o + \gamma_1 I_{t-1} + \gamma_2 \Delta^e_{t+1} + \gamma_3 i_t + \gamma_4 Y_t,$$

where the γ_j (j=0, ..., 4) are constants, and where i_t is a proxy for the opportunity costs of storage in period t.

We assume that the LME copper futures price can be interpreted as market anticipation of rationally acting participants, a hypothesis supported by the research of many authors studying the copper futures market[1]. Thus, the difference between the LME three months futures price and the LME spot price is proportional to the expected price change. We assumed that this rational expectations hypothesis is correct, and we estimated the coefficients of the storage equation derived above for the refined copper stocks at the London Metal Exchange, in the Federal Republic of Germany, in Japan, in the United States, and in all other market economies together.

However, most of the estimated equations did not adequately reflect the large build-up of inventories after the period of excessive speculation and during the world-wide recession in the mid 1970s. Therefore, to capture these extraordinary events, we had to introduce dummy dependent variables.

As an example for the estimated inventory equations we present the equation explaining the demand for storage in the Federal Republic of Germany.

Equation 3:

Estimated Inventory Equation, Federal Republic of Germany

[1] See e. g. Burley [1974], Goss [1981], Gupta, Mayer [1981] or Gilbert [1982].

$$STGE = \underset{(.238)}{1.96} + \underset{(1.78)}{.277}\ STGE_{-1} - \underset{(-1.00)}{2.01}\ INTGE + \underset{(1.74)}{.0325}\ (PCULMEF$$

$$- PCULME)\ .\ REXGE\ /\ REXUK + \underset{(3.43)}{.695}\ IIPGE + \underset{(3.74)}{43.9}\ D77,$$

$$\bar{R}^2 = .888, \qquad DW = 2.00,$$

where

STGE = Refined copper stocks, Federal Republic of Germany, in 1000 tons,

INTGE = Discount rate, end of period, Federal Republic of Germany,

PCULMEF = Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, futures, Pound sterling per ton,

D77 = Dummy variable, 1 in 1977, 0 otherwise.

The other abbreviations are defined above.

The estimation results for all inventory equations can be summed up as follows:

1. The flexible accelerator hypothesis of stock adjustments is confirmed by the asymptotic t-statistics of the parameters of the lagged endogenous variables in all estimated storage equations. Generally, the adjustment speed is high due to the fact that copper stocks are traded on a daily basis.

2. The difference between LME copper futures and spot price converted to local currencies always has the sign expected a priori, and the estimated parameters are always significantly different from zero. This supports the above rational expectations hypothesis in regard to the short-term behavior of LME futures prices.

3. Interest rates do not always prove to be good proxies for the opportunity costs of storage. In two cases, the estimated coefficients of various interest rates always

had the wrong sign. But they also were not significantly different from zero, and therefore, the interest variables were skipped.

4. In all estimated equations, the transaction requirements for inventories depend on the size of the output of the copper-using industries, measured by the index of industrial production, or directly on the amount of copper consumed. The signs of the estimated coefficients are always correct and they are always significantly different from zero.

3. Supply Equations

3.1 Primary Production

Theoretical Considerations

The estimation of primary copper supply equations in our model is based on the assumption that mine production capacities are given in the-short run, and that producers maximize their profits given this short-term constraint.

The hypothesis that copper producers consider their mine capacity to be given in the short-run, and that they maximize their profits under this constraint, is plausible, because our model is based on annual data, and because the gestation period in mine production capacity expansions is substantial, a year at least in any case, even for short-run expansions.

Data restrictions prohibited the application of sophisticated economic theory, so it was assumed that a generalized Cobb-Douglas production function sufficiently describes the technology of copper production.

The world copper market is essentially competitive, disregarding certain oligopolistic structures in the North American copper industry, which have experienced increasing competitive pressures in the last few decades. The history of copper pricing shows that no single copper producing country has been able to influence the copper world market price by its actions effectively. We therefore assume that each copper producer is a competitive price-taker and that he chooses output and variable factor input which maximize his profits.

From the necessary condition resulting from this simple optimization problem, we obtain a factor demand function, which leads to a restricted gross profit function, where the costs of capacity expansions can be neglected, because they are fixed in the short-run. If input and output prices are positive, the supply function of a copper producer is nothing but the partial derivative of the gross profit function in respect to output price (Hotelling's lemma"). If we finally add a stochastic error term with the usual properties, then the estimating equation can be written

$$\log Q_t = \delta_0 + \delta_1 \log(\frac{P_t}{V_t}) + \delta_2 \log K_t + w_t,$$

where Q_t denotes copper mine production, V_t a unit cost of mining index, K_t the mine production capacity, w_t a stochastic error term, and δ_0, δ_1, δ_2 are constant parameters.

The econometric model includes such primary supply equations, which have been estimated for the eight most important copper mining market economies (Canada, Chile, Peru, the Philippines, South Africa, the United States, Zaire and Zambia), as well as for the rest of the Western World together. For the centrally planned economies no information about mine production capacities was available, such that a modified equation had to be estimated[1].

A Representative Equation

As a typical example for a primary copper supply equation, we present the estimated equation for Zaire's mine production.

<u>Equation 4</u>:

Estimated Mine Production Equation, Zaire

$$\log(QMZI) = \underset{(1.39)}{.320} + \underset{(33.4)}{.868} \log(QMZIC) - \underset{(-6.97)}{.149}\, DZI + \underset{(3.12)}{.0562}$$

$$\log((PCULME \,.\, REXZI) \,/\, (REXUK \,.\, COSTTI)),$$

$$\bar{R}^2 = .981, \qquad DW = 2.49,$$

where

QMZI	= Copper mine production, Zaire, in 1000 tons,
QMZIC	= Copper mine production capacity, Zaire, in 1000 tons,
PCULME	= Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound sterling per ton,
REXZI	= Exchange rate, Zaires per US Dollar,
REXUK	= Exchange rate, Pound sterling per US Dollar,
COSTZI	= Unit cost of mining index, Zaire, 1975 = 1.00,
DZI	= Dummy variable for Katanga war, 1 in 1963 - 1965, 0 otherwise.

[1] In explaining the centrally-planned economies' primary copper production we assume that their copper output depends on the level of general economic activity in these countries and on a time trend as well.

The signs of the estimated coefficients are as expected from economic theory; all coefficients are significantly different from zero and have magnitudes which are plausible a priori.

We sum up the most important estimation results for the copper mine production equations:

1. All coefficients of all estimated primary supply equations have the expected signs, and

2. all coefficients are significantly different from zero (at the 5 % level), with the exception of two price elasticities of supply (South Africa and "other market economies").

3. Contrary to most econometric copper market models with a similar degree of disaggregation only few dummy variables had to be introduced, namely for the Katanga war, and for strikes in Canada and in the United States.

This concludes the description of the primary copper supply equations, and we turn now to the secondary supply equations.

3.2 Secondary Supply Equations

Primary and secondary refined copper is practically identical for most uses of copper. Therefore the determinants of secondary supply resemble the factors which affect primary supply, and therefore depends on relative prices (in domestic currency). Depending on the grade of copper or copper alloy scrap, and on conversion charges, the LME copper prices and scrap prices are more or less highly correlated. Therefore scrap supply depends on the LME price, either directly or indirectly, like in the United States, where a domestic copper scrap price is generally used. Apart from U.S. data, no separation of secondary copper according to its source (old or new scrap) is available. Therefore we estimated a hybrid approach, including variables explaning secondary supply from new scrap and variables determining secondary supply from old scrap. Due to lack of capacity figures for secondary producers, it was not possible to choose the same approach as for primary supply modeling. Therefore we assumed a simple partial adjustment hypothesis in explaining the secondary copper supply.

Summing up these considerations, secondary copper supply depends on output of copper-using industries. If the stock/consumption ratio in a country was significantly different from zero (at the 5 % level), then it was also included as an explanatory variable.

Representative Equations

As example of secondary copper supply equations we present secondary copper supply equations for the Federal Republic of Germany and for the United States.

<u>Equation 5</u>:

Estimated Secondary Supply Equation, Federal Republic of Germany

$$QSGE = \underset{(1,42)}{30.4} + \underset{(1.24)}{.219}\ QSGE_{-1} + \underset{(2.25)}{.439}\ ((PCULME\ .\ REXGE)\ /\ (REXUK\ .\ PWIGE)) + \underset{(3.95)}{.804}\ IIPGE,$$

$$\bar{R}^2 = .682, \qquad DW = 2.09,$$

where

QSGE = Production of refined copper from scrap, Federal Republic of Germany, in 1000 tons,

PCULME = Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound sterling per ton,

REXGE = Exchange rate, Deutsche Mark per US Dollar,

REXUK = Exchange rate, Pound sterling per US Dollar,

PWIGE = Price index of industrial output, Federal Republic of Germany, 1975 = 1.00, and

IIPGE = Index of industrial production, Federal Republic of Germany, 1975 = 100.

Equation 6:

Estimated Secondary Supply Equation, United States

$$QSUS = \underset{(-.727)}{-24.8} + \underset{(4.23)}{.383}\, QSUS_{-1} + \underset{(3.26)}{8.30}\, PSUS / PWIUS - \underset{(-3.65)}{505}\, STUS / QCUS + \underset{(6.81)}{2.32}\, IIPUS - \underset{(-1.37)}{41.1}\, D67,$$

$$\bar{R}^2 = .927, \qquad DW = 2.24,$$

where

QSUS = Production of refined copper from scrap, United States, in 1000 tons,

PSUS = Average annual price, dealers' No. 2 heavy copper scrap, US Dollar per ton,

PWIUS = Wholesale price index, general United States, 1975 = 1.00,

STUS = Refind copper stocks, United States, in 1000 tons,

QCUS = Total copper consumption, United States, in 1000 tons,

IIPUS = Index of industrial production, United States, 1975 = 100,

D67 = Dummy variable for strike in US copper industry, 1 in 1967, 0 otherwise.

In these equations, the signs of all estimates coefficents are correct, and some parameters are highly significant. The results for the other secondary supply equations are similar, but generally the fit is not as good as for the primary supply equations.

4. Other Equations

4.1 Prices

LME Spot Price

The determination of the London Metal Exchange cash price for electrolytic copper, wirebars, follows closely the dynamic stock disequilibrium model of price adjustment, discussed and applied by Hwa (1979). Additionally, dummy variables for U.S. export and price controls and for the excessive speculation against the Pound sterling in 1978/79 are included. Contrary to Hwa's approach, not current output, but lagged mine production levels affect price levels significantly. Equation 7 presents the estimation result.

Equation 7:

Estimated Price Equation, London Metal Exchange, Spot Price

$$\begin{aligned} PCULME = & \underset{(-1.48)}{-88.4} + \underset{(4.15)}{.0661}\,QCWW - \underset{(-0.16)}{.0081}\,STWW_1 \\ & + \underset{(7.09)}{9.19}\,EUVI \cdot REXUK + \underset{(5.94)}{154}\,DEX - \underset{(-2.01)}{120}\,D78, \\ & - \underset{(-1.91)}{0.049}\,QMWW_{-1}, \end{aligned}$$

$$\bar{R}^2 = .959, \qquad DW = 1.41,$$

where

PCULME = Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound sterling per ton,

QCWW	= Total copper stocks, market economies, in 1000 tons,
EUVI	= Index of export unit values, industrialized countries, 1975 = 1.00,
REXUK	= Exchange rate, Pound sterling per US Dollar,
DEX	= Dummy variable for US copper export and price controls,
D78	= Dummy variable for excessive speculation against the Pound sterling, and
QMWW	= Copper mine production, market economies, in 1000 tons.

LME Futures Price

The LME futures price is determined primarily by the same fundamentals of world demand and supply as the cash price and therefore depends on this price. Exchange rate developments influence hedging, speculation and arbitrage conditions on the futures market. Therefore, the futures price depends also on the Pound sterling/US dollar exchange rate. Finally, the gold price reflects speculative price expectations on the precious metal slopping over the copper market.

Summing up these considerations, the following equation was estimated

Equation 8:

Estimated Price Equation, London Metal Exchange, Future Price

$$\text{PCULMEF} = \underset{(-6.22)}{-92.7} + \underset{(54.7)}{.913}\ \text{PCULME} + \underset{(6.47)}{304}\ \text{REXUK} + \underset{(3.54)}{.0756}\ \text{PAU},$$

$$\bar{R}^2 = .998, \qquad DW = 1.94,$$

where

PCULMEF = Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, futures, Pound sterling per ton,

PAU = Average annual price of gold, US Dollar per fine ounce

The other variables are defined above.

Other price equations

Apart from these competitive prices, determined at the London Metal Exchange, our model accounts for the US Scrap price, which depends on the LME futures price, and it recognizes the existence of producer price systems in North America, and - in the early 1960s - in Chile.

The next table presents the example of the Canadian producer price, the US producer price equation looks very similar. The equation takes account of the fact that Canadian copper producers are able to shift their production costs to a certain extent, but, due to competitive import pressures, the domestic price also depends on the world market fundamentals which determine the LME prices. In Canada and in the United States the same dummy dependent variables had to be introduced to allow for the end of US export controls in 1970 and for the end of price controls in 1974.

<u>Equation 9:</u>

Estimated Price Equation, Canada, Producer Price

$$PCUCA = \underset{(-4.67)}{-10.1} + \underset{(6.74)}{.0171}\ PCULME \cdot REXCA / REXUK$$

$$+ \underset{(12.0)}{54.3}\ COSTCA + \underset{(1.32)}{5.29}\ D70 + \underset{(1.64)}{6.94}\ D74,$$

$$\bar{R}^2 = .975 \qquad DW = 1.26,$$

where

PCUCA	= Average annual price of copper, electrolytic copper wirebars, Canadian producers, Canadian cents per lb.,
REXCA	= Exchange rate, Canadian Dollars per US Dollar,
COSTCA	= Unit cost of mining index, Canada, 1975 = 1.00,
D70	= Dummy variable, 1 in 1970, 0 otherwise,
D74	= Dummy variable, 1 in 1974, 0 otherwise.

The other variables are defined above.

We now turn to the explanation of copper mine production capacities, a topic neglected by most econometric copper market models.

4.2 Copper Mine Production Capacities

Theoretical Considerations

The derivation of mine production capacity equations assumes that copper producers maximize the present value of all future net revenues accruing to their company over time, i. e. they maximize the present value of all future net cash flows[1].

Let capacity be proportional to the capital stock, and capital stock proportional to the flow of capital services. Then a producer increases capacity, if the marginal discounted net revenue exceeds the purchase price of an additional unit of capital services. As above, we assume that a generalized Cobb-Douglas production function describes copper mining activities sufficiently. If a copper producer maximizes his discounted net cash flow, then desired capacity is determined by the marginal productivity condition for capital, i. e. the value of the marginal product of capital equals the

[1] See Wagenhals [1984b] for a detailed derivation of the estimating equations.

user cost of capital. The user cost of capital is the implicit rental price for a unit of capital and depends on capital prices, interest rates, depreciation charges, corporate tax rates, and depreciation methods used, i. e. straight line depreciation for all countries and regions but the United States, where the sum of the years' digits depreciation method has been assumed. The US user cost of capital equation also takes into account investment credits and the 1962-63 Long Amendment.

Copper producers cannot adjust immediately to optimal capacity levels, which usually differ from actual capacities. We therefore assume a flexible accelerator hypothesis of stock adjustments for capacity adjustments.

These considerations finally lead to the following copper mine capacity equation

$$K_t = \eta_0 + \eta_1 K_{t-1} + \eta_2 \frac{P_t Q_t}{c_t} + u_t,$$

where

K_t = copper mine production capacity,
P_t = price of copper,
c_t = user cost of capital index,
Q_t = copper mine production,
u_t = error term,
η_0, η_1, η_2 are constants.

Equations of this type were estimated for Canada, Chile, Peru, the Philippines, South Africa / Namibia, the United States, Zaire, Zambia and for the "rest" of the market economies together.

A Representative Equation

As an example, Equation 10 presents the mine production capacity equation for Canada.

Equation 10:

Estimated Mine Production Capacity Equation, Canada

$$QMCAC = \underset{(.232)}{4.71} + \underset{(26.1)}{.901}\ QMCAC_{-1} + \underset{(3.46)}{.178}\ PCUCA \cdot QMCA / UCCA,$$

$$\bar{R}^2 = .981 \qquad DW = 1.74,$$

where

QMCAC = Copper mine production capacity, Canada, in 1000 tons,

QMCA = Copper mine production, Canada, in 1000 tons,

UCCA = User cost of capital index, mining, Canada, 1975 = 100.

PCUCA is defined above.

Equation 10 shows that Canada's lagged capacity level is the main determinant of the current level. The mine capacity adjusts slowly to price changes. The Canadian capacity elasticity with respect to prices (evaluated at the mean) is small, but higher than the corresponding elasticities of the developing copper producers.

We sum up the estimation results for the copper mine production capacity equations:

1. With only one exception (the Zambian capacity equation), the constant terms of all copper mine production capacity equations are not significantly different from zero. This supports the above a priori assumption of discounted net cash flow maximization, because it is implied by this hypothesis.

2. The estimated coefficients of the lagged endogenous variables are highly significant in all equations. They always have the expected signs and magnitudes.

3. Although developing countries always adjust to price changes in the direction expected a priori, their mine capacities generally adapt very slowly and only weakly. In contrast to these results, capacity changes of the main copper producers among the industrialized market countries, namely of Canada and the United States, very highly depend on prices: the respective price elasticities are significantly different from zero at the 0.5 % level. Thus, the industrialized copper producers react far more on price incentives than the developing economies.

4. After the nationalization or at the beginning of a majority ownership in the host country, the capacity behavior of Chile, Peru, and Zaire changed significantly. F-tests indicated structural breaks in the respective equations. This fact indicates that state mining enterprises in developing copper exporting countries - in some cases at least - pursue other long-run goals than maximization of the discounted net cash flow, for example optimization of foreign exchange earnings, output, employment, tax earnings or a combination of such goals. Currently, sufficient data is not yet available to test such hypotheses empirically.

4.3 Closing the Model

Apart from some identities, two behavioral equations close our model, namely a refined copper production equation for the United States, and an East-West net trade equation.

US refined copper production depends on the amount of copper mine output available and on the current stock/consumption ratio as well as on the same exogenous variables as US mine production.

The level of East-West trade depends on the centrally planned economies' excess supply, on the world market price, and on the level of industrial activity in the market economies. Long-term contracts and other restrictions lead to lagged adjustments.

These few remarks conclude the survey of our econometric model of the world copper industry, we now refer to validation experiments carried out by the author.

4.4 Validation Experiments

To validate the econometric world copper market model discussed above, we performed a historical dynamic simulation based on the values of the exogenous variables from 1956 to 1980 and based on the starting values of the endogenous variables in 1955. The model was solved simultaneously with the historical values of the exogenous variables and with the values predicted by the model in the previous period for the lagged endogenous variables.

Calculation of many goodness of fit measures for this historical dynamic solution suggested that the model traces the main historical developments of the world copper market quite well. It is beyond the scope of this study to present the detailed results here. They are quite similar to the results presented in Wagenhals [1983a, pp. 163-4]. Due to a slight respecification of the LME spot price equation and the mine production capacity equations the goodness of fit statistics presented there generally improved.

The model captures most of the turning points in the historical development of the world copper industry since the mid 1950s. Ex post, it describes the time paths of the most important variables quite well.

This assertion was also confirmed by a series of dynamic multiplier simulation experiments reflecting the dynamic response properties of the model. Estimation results, validation tests and simulations experiments suggest that the current model may be a useful tool to perform forecasting exercises and to analyze the effects of copper production from manganese nodules on land-based production, consumption and prices of copper, which is the prupose of the following last part of this paper.

III THE EFFECTS OF COPPER PRODUCTION FROM MANGANESE NODULES

This part of the report describes the results of a series of forecasting and simulation experiments performed with the econometric model described above. The first section explains the assumptions underlying the estimates of the exogenous variables, then the base case forecasting results (without seabed mining) are presented. The last section finally compares the base case results with three scenarios, which differ in regard to the assumptions as to how much copper is extracted from manganese nodules.

1. Assumptions Underlying the Forecasts

The values of most future exogenous variables used in our forecasting exercises are derived from or based on the most recent macroeconometric forecast update of Data Resources, Inc., published in September 1983. Our exogenous variables for the industrialized market economies (Canada, Germany, Italy, Japan, United States, United Kingdom, total Western World), i. e. indices of industrial production, exchange rates, wholesale price indices and interest rate forecasts (or their percentage changes) are taken from this source without changes. Unit costs of mining and user costs of capital are assumed to grow in line with projected producer price changes in the United States, assuming constant exchange rates at the 1982 level for the developing economies and for the Republic of South Africa. For Canada a forecast of the domestic wholesale price changes was available from DRI, for the aggregate "other market economies" mining cost growth in line with the World Bank's MUV index (explained below) was assumed. For the centrally planned countries a constant 3 % growth rate of industrial production was stipulated.

Future values of commodity prices are taken from the most recent forecasts of the Commodities and Export Projections Division [World Bank, 1983a]. The gold price is assumed to grow in line with their projections of the manufacturing unit value (MUV) index, i. e. the unit value index of manufactured exports (SITC 5 - 8) from industrial to developing countries on a cif basis [World Bank, 1983a, p. 28]. We also use the Division's forecast of the US aluminum price, and we assume the the LME aluminum price grows with the same rate.

A projection for the LIBOR Eurodollar rate was not available, therefore DRI's forecast of the US long-term bond yield was used instead. Furthermore we assume that the index of the industrialized countries' export unit values grows with the same rates as the DRI's composite wholesale price index for the major European countries.

In the description of the econometric model above, we ascertained a structural break in the mine production capacity equations of Chile, Peru, and Zaire. Thus, we cannot use these equations, which have been estimated under the assumption that these copper producers maximize their net cash flow, to predict the future development of their capacities. Instead, we assume that the following copper mine expansions will take place[1]:

Chile:	1983	Anina, Min Sur-Sur orebody.
	1985-1995	El Teniente, phased ten-year program.
	1986	Expansion of Dispudada.
Peru:	1984	Tintaya, Cuajone.
	1985	Second Stage expansion of Cerro Verde.
Zaire:		No major capacity expansions are planned.

---

[1] See Engineering and Mining Journal, [January 1983, p. 50], and Metallgesellschaft AG's Pressemeldungen über die Metallmärkte, various issues.

Eventually, very heroically, we assume that the balancing surplus of copper, not reported as stocks, will be zero from 1983 on.

Qualifications

Naturally, the forecasts presented below are conditional forecasts. They critically depend on the assumptions made in regard to the economic development beyond the early 1980s. If the economic situation will differ significantly, then the forecasts have to be revised accordingly. Current uncertainties regarding the likely growth rates, inflation and exchange rate developments are substantial. Therefore, our forecasting exercise cannot be expected to present the actual values of all projected variables in any year of the forecast horizon. The high past volatility of copper prices, compared with other commodity prices, suggests that short-term variations may also be considerable in the future, and that actual future values of prices and quantities may differ from our projections.

But our forecasts are based on the most likely economic assumptions concerning the future development of the major copper producing and consuming countries as it is reflected in the forecasts of Data Resources Inc., of the World Bank's Commodities and Exports Projections Division and in the author's own judgement. They indicate, what is likely to happen in the world copper industry, if no major structural breaks occur (possibly a heroic assumption for some of the developing copper producers), and if no major changes in government policies (especially of the US General Services Administration in regard to the official US copper stockpiling program) take place.

Given that all these assumptions are correct and taking into regard the qualifications mentioned, the forecasts of the most important variables in the world copper industry presented below may serve as indications about the most likely broad future development of these variables.

2. Forecasts of the Endogenous Variables

2.1 General Remarks

This section presents the base case forecasts obtained with our econometric model of the world copper market under the set of assumptions described above.

Our copper production forecasts for some producers (e. g. for Canada, Chile, and the United States), and our consumption projections for some industrialized countries (e. g. for Japan and the United States) are higher than the corresponding World Bank forecasts, published in July 1983 [World Bank, 1983b]. On the other hand, our projections of the centrally planned economies' and for the total world's consumption are somewhat lower.

These differences largely reflect diverse assumptions in regard to the future development of the exogenous variables. Our forecasts for the exogenous variables are more recent (i. e. of August/September 1983), and therefore they may be somewhat more reliable than the World Bank's projections.

2.2 Demand Forecasts

The following tables present our copper demand base forecasts. The projections of refined copper consumption are projected very detailed, the demand for copper in all forms, i. e. including the direct use of copper and copper alloy scrap, and the demand for storage are only briefly referred to on an aggregate level.

First, Table 12 shows detailed results for the refined copper consumption in the world's main copper consuming countries and regions, then Figure 5 shows the actual and projected development of refined copper consumption in the market economies and in the total world.

Table 12 - Projections of Refined Copper Consumption, 1983 - 1995, in 1000 tons

Year	Countries / Regions							
	Germany F. R.	Italy	Japan	United Kingdom	United States	Other market econo-mies	Market econo-mies	Total World
1983	750	347	1398	391	2078	2310	7273	9811
1984	747	351	1377	389	2177	2388	7429	10020
1985	831	377	1585	381	2245	2598	8016	10660
1986	834	389	1655	375	2297	2686	8236	10930
1987	849	397	1739	374	2350	2788	8498	11250
1988	862	407	1829	371	2400	2886	8756	11560
1989	884	419	1914	369	2444	2986	9016	11880
1990	903	426	2029	364	2491	3090	9303	12220
1991	915	433	2152	360	2536	3194	9590	12570
1992	923	445	2253	356	2579	3191	9846	12890
1993	936	458	2343	353	2620	3389	10110	13210
1994	955	471	2497	355	2661	3503	10440	13610
1995	983	486	2653	353	2704	3625	10810	14030

Figure 5 - Actual (1950 - 1982) and Projected (1983 - 1995) Copper Consumption, Market Economies (B) and Total World (A)

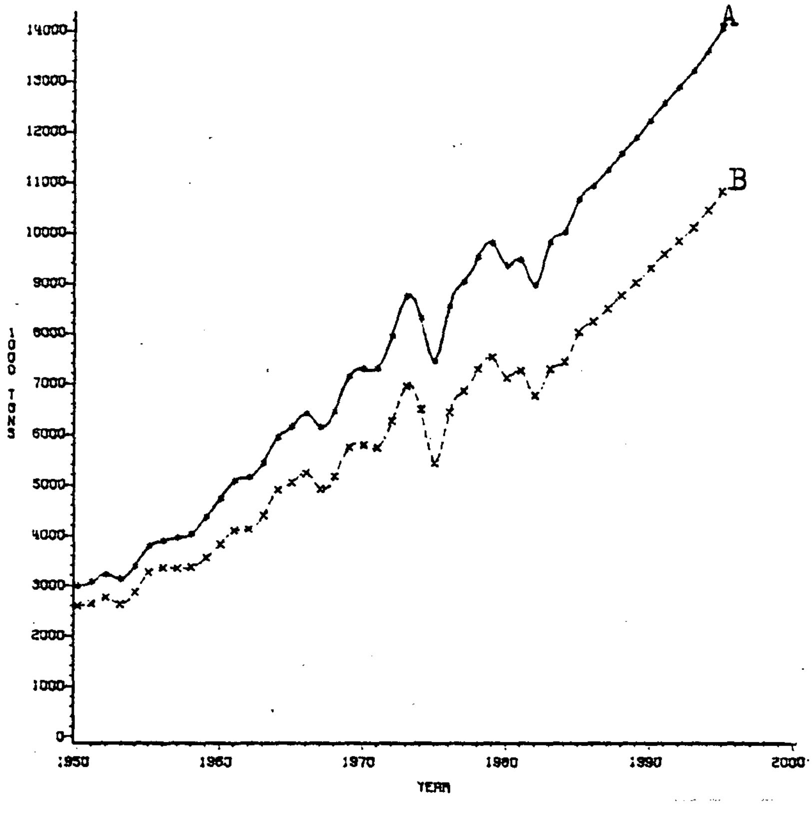


Table 13 lists the forecasts of the agregate private inventory holdings and of the total use of copper (including direct use of scrap) in all market economies together.

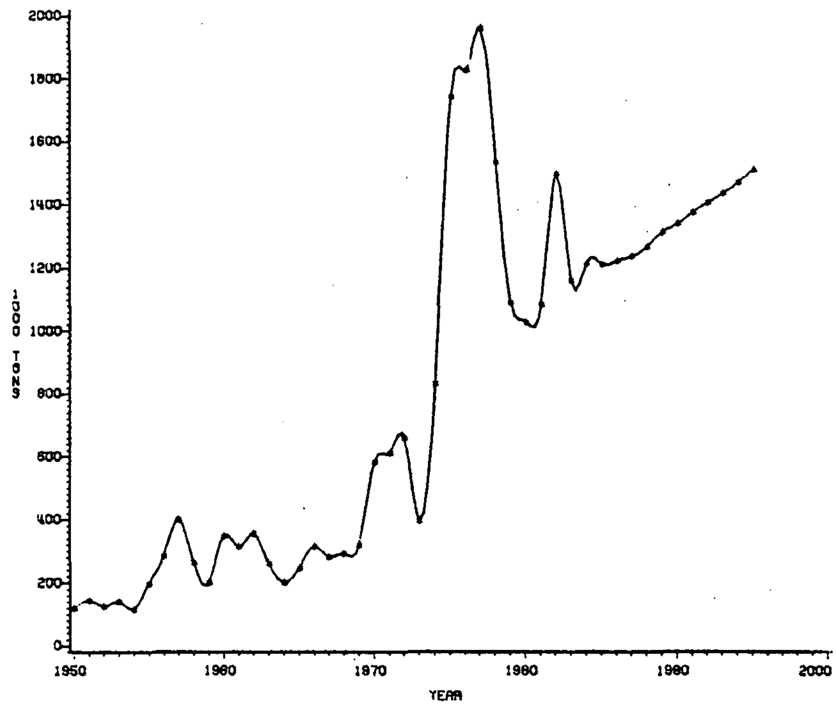
Table 13 - Projections of Total Private Inventories, of Total Copper Use, and of their Ratio, 1983 - 1995, Market Economies

Year	Inventories	Total consumption	Ratio
1983	1161	9770	11.9
1984	1218	9968	12.2
1985	1212	10705	11.3
1986	1224	10983	11.1
1987	1238	11311	10.9
1988	1268	11635	10.9
1989	1315	11962	11.0
1990	1340	12321	10.9
1991	1377	12679	10.9
1992	1408	13001	10.8
1993	1437	13328	10.8
1994	1472	13752	10.7
1995	1512	14207	10.6

On an average, total copper consumption is expected to grow some 3 % annually between 1983 and 1995, private copper stocks will increase some 2 %, such that the stock / consumption ratio will decline approximately one percentage point. Private stockholding will decrease even more, if official stockpiling in Japan is resumed, if the US Administration increases the level of its currently very low copper stockpile, or if the West German, French or any other European government decides to start with strategic copper stockpiling.

Figure 6 shows the historical and projected development of private refined copper stocks in the market economies under the assumption that no additional official stockpiling will take place during the forecasting horizon of the model. The currently unusually high stock / consumption ratio will not be sustained in the late 1980s and the 1990s, it will return to normal levels, but it will remain slightly above its long-term average before the mid 1970s.

Figure 6 - Actual (1950-1982) and Projected (1983-1995) Private Refined Copper Stocks, Market Economies, in 1000 tons



2.3 Supply Forecasts

Now we turn to the forecasts of copper supply from ores and concentrates (primary supply) and of copper supply from scrap (secondary supply). Figure 7 shows the historical and projected development of the aggregated variables for the market economies and the following tables present the detailed projections of all supply variables explained by the model.

Figure 7 - Actual (1956-1982) and Projected (1983-1995) Copper Output, Primary (B), Secondary (C) and Total (A) Production, Market Economies, in 1000 tons

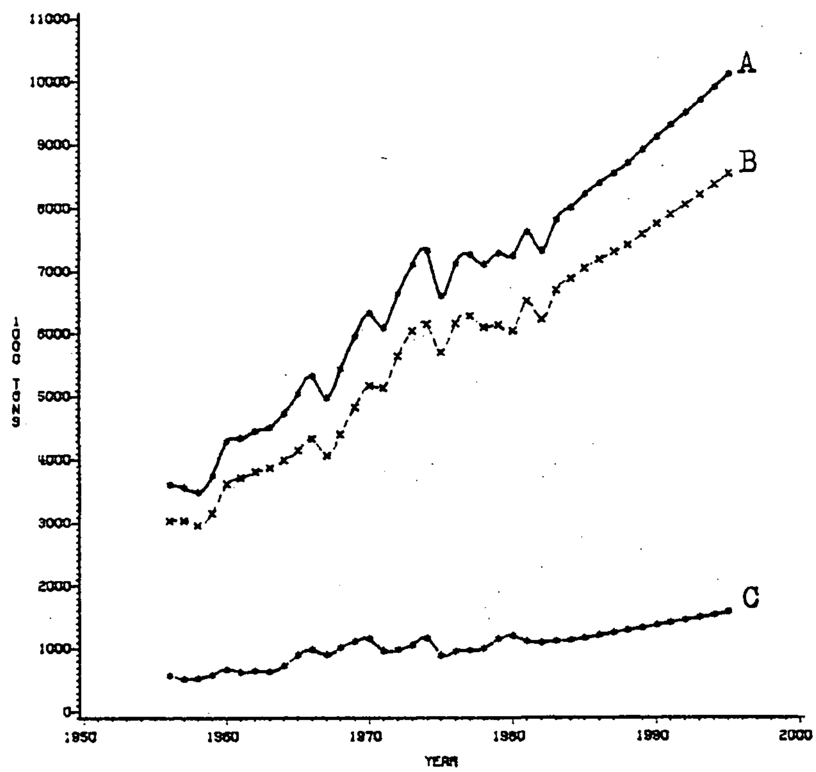


Table 14 - Projections of Primary Copper Production, 1983 - 1995, in 1000 tons

Year	Countries					
	Canada	Chile	Peru	Philip-pines	South Africa/ Namibia	United States
1983	828	1209	344	383	257	1388
1984	847	1259	393	402	261	1387
1985	871	1315	407	424	265	1389
1986	894	1332	419	446	268	1389
1987	919	1341	420	470	272	1390
1988	943	1349	421	494	276	1390
1989	968	1357	464	520	280	1391
1990	994	1365	508	547	285	1392
1991	1022	1373	520	576	289	1393
1992	1050	1380	531	606	293	1394
1993	1079	1388	543	638	298	1395
1994	1109	1396	555	672	303	1396
1995	1140	1404	567	708	307	1398

Table 14 continued

Year	Zaire	Zambia	Other Market Economies	All Market Economies	Centrally Planned Economies	Total World
	Countries / Region					
1983	501	560	1221	6692	2043	8735
1984	501	561	1265	6877	2101	8979
1985	502	564	1315	7052	2160	9211
1986	503	565	1365	7182	2217	9399
1987	503	566	1418	7298	2274	9573
1988	504	567	1473	7417	2331	9749
1989	504	568	1531	7583	2388	9971
1990	504	569	1592	7755	2446	10201
1991	505	570	1655	7901	2503	10404
1992	505	571	1721	8052	2560	10612
1993	505	571	1790	8207	2618	10825
1994	505	572	1863	8371	2675	11046
1995	506	573	1938	8541	2733	11274

Table 15 - Projections of Secondary Copper Production, 1983 - 1995, in 1000 tons

Year	Germany	Japan	United States	Market Economies
	Countries / Region			
1983	173	129	411	1120
1984	175	128	418	1133
1985	176	141	436	1175
1986	179	148	452	1213
1987	182	155	469	1253
1988	186	162	484	1293
1989	189	169	497	1331
1990	193	179	509	1372
1991	196	189	522	1414
1992	198	198	534	1453
1993	201	205	545	1491
1994	205	217	555	1533
1995	211	230	566	1580

2.4 Forecasts of Prices and Other Variables

This section presents the forecasts of prices and other important variables. The following two plots show the development of actual and projected copper prices in current US-Dollar and in constant 1982 US-dollar (deflator is the US BLS producer price index). Table 16 presents detailed figures.

Table 16 - Projections of Copper Prices, 1983 - 1995

Year	Current prices		1982 US-Dollar	
	LME spot £/ton	US producers US-$/ton	LME spot US-cts/lb	US producers US-cts/lb
1983	1083	1875	.7359	.8505
1984	1373	2463	.8885	1.0470
1985	1404	2636	.9358	1.0600
1986	1492	2798	.9534	1.0630
1987	1618	2972	.9727	1.0670
1988	1790	3173	.9857	1.0700
1989	1964	3381	.9991	1.0720
1990	2124	3609	1.0160	1.0760
1991	2331	3857	1.0260	1.0780
1992	2553	4115	1.0360	1.0790
1993	2795	4390	1.0430	1.0800
1994	3079	4670	1.0570	1.0830
1995	3398	4963	1.0690	1.0860

Our projections suggest that copper prices at the London Metal Exchange and in the United States will rise to some US-Dollar 5 000 per ton in the mid 1990s, which is, compared with the 1980 figures, an average annual growth of more than five per cent. But, according to DRI's US forecasts of annual producer price changes, this growth rate is not substantial enough to compensate for general inflation, so that the "real" copper prices in the mid 1990s will be even slightly below their 1980 levels. Thus, no significantly increasing trend in copper prices can be expected in the next decade.

The current depressed situation of copper prices will improve only very slowly. In the 1980s, US producer prices will be higher than the corresponding LME prices, possibly high enough to cover the variable costs of many mines in that country. But this price spur induces import pressures, hampers US competitiveness and leads to very small growth rates in US primary copper production. At least in the 1980s many copper mining enterprises will still work with losses.

Figure 8 - Actual (1954 - 1982) and Projected (1983 - 1995) Copper Price, Electrolytic Copper, Wirebars, LME Spot Price (A) and US Producer Price (B), in current US-Dollar per ton

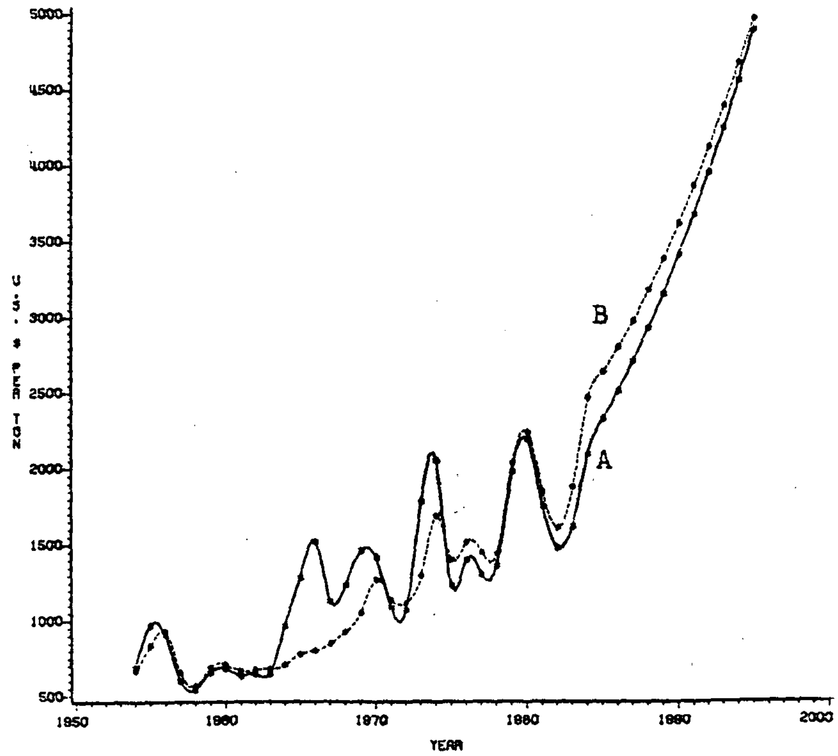
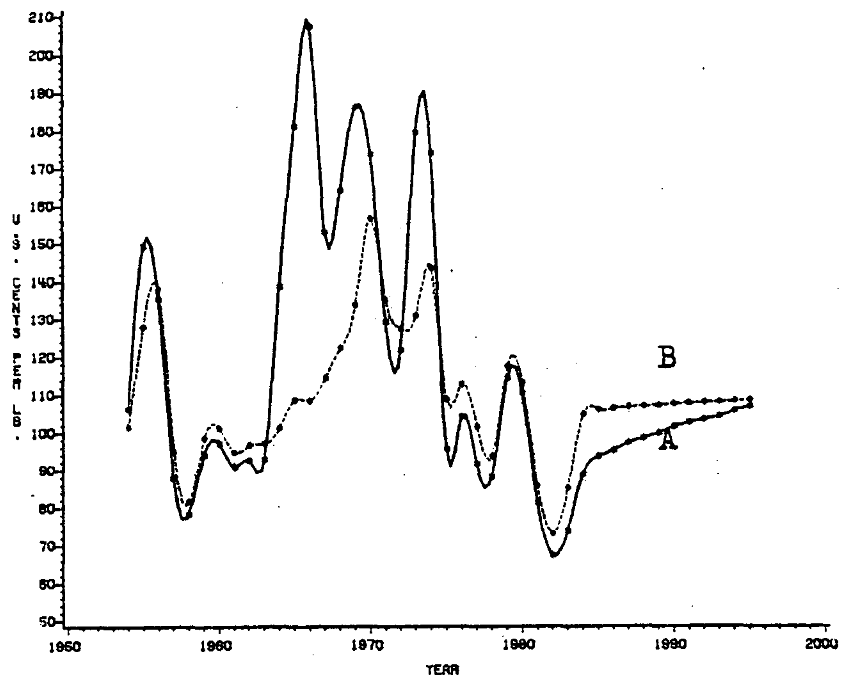


Figure 9 - Actual (1954 - 1982) and Projected (1983 - 1995) Copper Price, Electrolytic Copper, Wirebars, LME Spot Price (A) and US Producer Price (B), in 1982 constant US-cents per lb



The Canadian and Chilean producer prices as well as the LME future price and the US scrap price projections are very similar to the LME spot price forecasts, therefore they are not presented here.

Finally, Table 17 shows the projections of copper mine production capacities for the countries and regions, where the hypothesis of discounted net cash flow maximization could not be rejected and for all market economies together. Appendix C includes a listing of our assumptions regarding capacity expansions in Chile, Peru and Zaire, which are exogenous in our forecast because of structural breaks in the behavior of these producers after nationalization or beginning of majority ownership in equities.

Table 17 - Projections of Copper Mine Production Capacities, 1983 - 1995, in 1000 tons

Year	Countries / Region					
	Canada	Philip-pines	South Africa/ Namibia	United States	Zambia	Other market economies
1983	983	456	271	1672	689	1714
1984	1008	480	275	1669	688	1818
1985	1036	505	278	1667	688	1929
1986	1064	532	282	1666	688	2047
1987	1095	560	286	1665	688	2175
1988	1126	590	290	1665	688	2311
1989	1159	622	294	1665	688	2457
1990	1192	655	298	1665	688	2613
1991	1227	691	303	1666	688	2781
1992	1263	729	307	1667	688	2960
1993	1301	769	312	1668	688	3152
1994	1340	811	317	1669	668	3357
1995	1381	856	322	1670	669	3577

The expansion of copper mine production capacities resembles the respective developments in primary copper production. Capacity growth rates are high for the aggregate "other Market Economies". In these countries, Ok Tedi in Papua New Guinea and Olympic-Dam in South Australia alone will probably account for capacity increases amounting to more than 100 000 additional tons per year (respectively) in the late 1980s. The strong mine capacity growth in the Philippines reflects the low operating costs for mines in this country. On the other hand, if the United States' current governmental environmental, health, and safety regulations and restrictions of copper exploration and mining on federal lands will not be relaxed, then our projections suggest only small capacity increases in this country, generally only existing mines will be expanded then.

The presentation of mine capacity expansion projections concludes the description of our base forecasting results. The next section compares these results with the corresponding figures for three scenarios of copper production from manganese nodules in the event of deep-sea mining.

3. Seabed Mining Scenarios

3.1 Basic Assumptions

This section compares the base case forecast presented in the last section with projections based on three hypothetical scenarios of copper production from manganese nodules.

Table 18 lists the assumptions underlying the simulation experiments[1].

Table 18 - Hypothetical Scenarios of Copper Production from Manganese Nodules, in 1000 tons

Year	Scenarios		
	Low	High	Stepwise expansion
1988	9.0	27.0	9.0
1989	9.0	27.0	12.6
1990	9.0	27.0	16.2
1991	9.0	27.0	19.8
1992	9.0	27.0	23.4
1993	9.0	27.0	27.0
1994	9.0	27.0	27.0
1995	9.0	27.0	27.0

1 At least five international consortia are interested in recovering manganese nodules from the north-east Pacific Ocean. With current technology the first generation of operations will have a capacity between one and three million tons nodules per year. In the low scenario, each mining group is assumed to operate a capacity of one million tons per year, in the second case, the high scenario, a capacity of three million tons is hypothesized. The stipulated amount of copper produced follows from the average copper concentration found in manganese nodules recovered in that Pacific region.

Compared with the world's current and projected copper production even the assumption of the high scenario, which assumes an output of 27 000 tons from deep-sea mining is very small: it amounts to only 0.285 % of the world's actual refined copper consumption in 1981, or to just 0.256 % of the projected refined copper production in 1985 (respectively to 0.193 % in 1995).

In relation to copper stocks, the high scenario assumption corresponds to less than 2 % of private copper inventories at the end of 1982. Or, in the first four months of 1983 average refined copper stocks at the London Metal Exchange, which are highly liquid, easily tradable and which are available in seven European countries, surpassed the extraction figure of the high scenario more than twenty times.

In spite of the highly respected statistical efforts of Metallgesellschaft AG and of the World Bureau of Metal Statistics, measurement errors in copper statistics are disturbingly high. The Commodities Research Unit (1978) found out that discrepancies in copper statistics over the period from 1956 to 1977 averaged 56 000 tons per year, in two of these years they added up to more than 100 000 tons. These figures are also considerably higher than our assumptions about copper extractions from deep-sea nodules in all three scenarios.

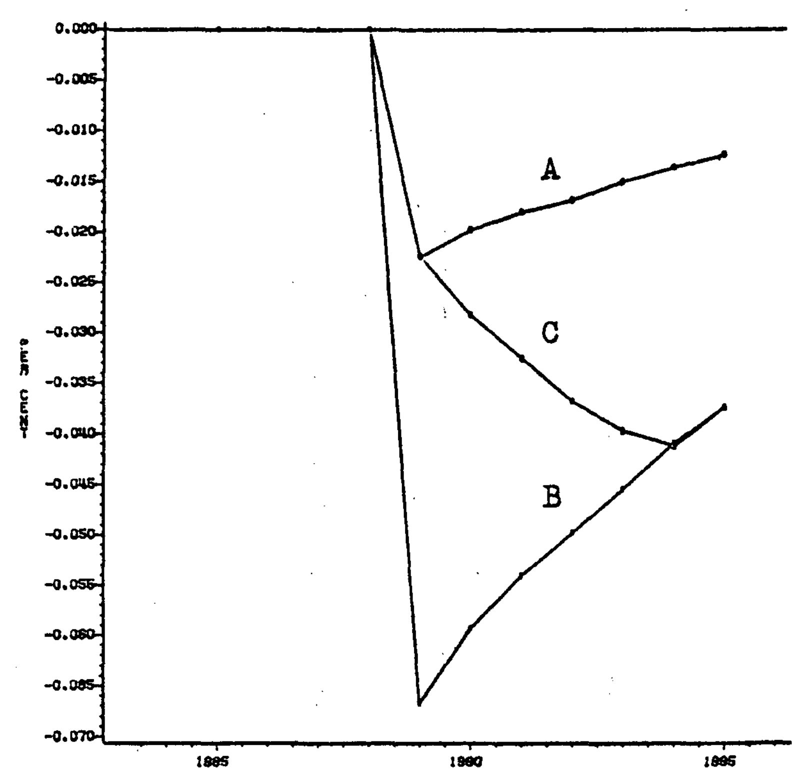
Thus, in relation to copper quantities actually produced, traded, stored, and consumed and in proportion to the size of ubiquitous measurement errors in copper statistics, 27 000 tons of copper recovered from three million tons of manganese nodules are very small.

Therefore we cannot expect copper extraction from deep-sea manganese nodules in the amounts assumed in Table 18 to have a sizeable effect on world copper output, trade, inventories, consumption, and prices. The following tables show that this presumption is correct. The deviations from the base case projections are extremely small, whichever of the three scenarios is considered. If we plot the results from the base case and the projected figures derived under any of the three scenarios, then the figures in the last section remain unchanged, because the changes in the base case forecast are too small to become visible, given the scale of the figures. It is possible, however, to plot the percentage deviations from the base case projections. Although these figures are quite small, they nevertheless allow to draw some conclusions about the likely impact of deep-sea copper mining on the world copper market, however small it may be.

3.2 Comparison of Base Case Forecasts with Scenario Projections

Figure 10 shows the deviations of the projections assuming low (Scenario 1), high (Scenario 2) and stepwise increasing (Scenario 3) copper production from manganese nodules from the base case forecasts.

Figure 10 - Average Annual LME Prices of Electrolytic Copper, Wirebars, Percentage Deviations from Base Case Projection in Scenario 1 (A), Scenario 2 (B) and Scenario 3 (C)



Tables 19 - 51 present the LME and US copper prices, and the deviation of the LME price from the base forecast. The following tables show detailed figures about the levels of production and consumption by countries in the base case and for the three scenarios.

An inspection of these tables shows that the beginning of copper production from ocean floor nodules in 1988 leads to a depressed copper price in the year after due to the additional supply. The more copper is extracted from manganese nodules, the more the price declines and the stronger is immediate impact of the price reduction in 1989.

The qualitative results of the model simulations in scenarios 1 and 2 are similar. In these cases the level of copper production from offshore deposits remains constant during the forecast horizon. Under this assumption, the world copper market begins to adjust already in the early 1990s. Annual copper consumption by countries increases, land-based production and copper mining capacities decrease. Supply effects are generally smaller than the demand effects, especially for the developing copper producing countries with their low supply elasticities, such that copper inventories increase somewhat. Adjustment processes are slow, but after some five years half of the initial price fall has been compensated. The forecast period is not long enough to show whether the time paths of prices and quantities in our scenarios will asymptotically reach the base case level, or whether prices will remain below the base forecasts. But, given the very low absolute effects of deep-sea mining on the copper market under the scenarios assumed here, this indecisiveness has no practical importance at all, because omnipresent stochastic disturbances are higher than the effects of ocean floor mining, at least in the long run.

In Scenario 3, which assumes a stepwise increase in copper supply from deep sea mining, the assumed annual additional copper output is high enough to put further downward pressures on prices until the constant production level of Scenario 2 is reached. Only then the market begins to adjust as described for scenarios 1 and 2 above.

Table 19 - Percentage Deviations from Base Forecast, 1988 - 1995

Year	Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound sterling per ton		
	Scenario 1	Scenario 2	Scenario 3
1988	0.000000	0.000000	0.000000
1989	-0.022406	-0.066708	-0.022406
1990	-0.019771	-0.059314	-0.028245
1991	-0.018016	-0.054047	-0.032600
1992	-0.016846	-0.049755	-0.036826
1993	-0.015026	-0.045436	-0.039712
1994	-0.013640	-0.040920	-0.041245
1995	-0.012360	-0.037375	-0.037375

Table 20 - Base Case and Scenario Projections, 1988 - 1995

Year	Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound Sterling per ton			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1790.47	1790.47	1790.47	1790.47
1989	1963.78	1963.34	1962.47	1963.34
1990	2124.27	2123.85	2123.01	2123.67
1991	2331.30	2330.88	2330.04	2330.54
1992	2552.51	2552.51	2551.24	2551.57
1993	2795.16	2795.16	2793.89	2794.05
1994	3079.18	3079.18	3077.92	3077.91
1995	3397.96	3397,96	3396.69	3396.69

Table 21 - Base Case and Scenario Projections, 1988 - 1995

Year	Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, in 1982 US-Dollar per Pound			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	.985695	.985695	.985695	.985695
1989	.999101	.998877	.998430	.998877
1990	1.01559	1.01539	1.01499	1.01530
1991	1.02648	1.02630	1.02592	1.02614
1992	1.03635	1.03618	1.03583	1.03597
1993	1.04338	1.04323	1.04291	1.04297
1994	1.05699	1.05695	1.05656	1.05655
1995	1.06915	1.06902	1.06875	1.06875

Table 22 - Base Case and Scenario Projections, 1988 - 1995

Year	Average annual price of copper, electrolytic copper, wirebars, US producers, US-Dollar per ton			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	3172.81	3172.81	3172.81	3172.81
1989	3380.82	3380.62	3380.23	3380.62
1990	3609.06	3608.86	3608.48	3608.79
1991	3857.05	3856.87	3856.49	3856.71
1992	4114.65	4114.46	4114.09	4114.23
1993	4389.92	4389.74	4389.37	4389.45
1994	4670.22	4670.05	4669.69	4669.69
1995	4962.64	4962.47	4962.13	4962.13

Table 23 - Base Case and Scenario Projections, 1988 - 1995

Year	Average annual price of copper, electrolytic copper, wirebars, US producers, 1982 US-Dollar per Pound			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1.06968	1.06968	1.06968	1.06968
1989	1.07227	1.07221	1.07208	1.07221
1990	1.07564	1.07559	1.07547	1.07556
1991	1.07756	1.07750	1.07740	1.07746
1992	1.07921	1.07916	1.07906	1.07910
1993	1.08022	1.08017	1.08008	1.08010
1994	1.08325	1.08321	1.08313	1.08312
1995	1.08585	1.08581	1.08573	1.08573

Table 24 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, Federal Republic of Germany, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	862.128	862.128	862.128	862.128
1989	884.336	884.336	884.336	884.336
1990	902.668	902.685	902.719	902.685
1991	914.564	914.579	914.609	914.585
1992	922.498	922.512	922.540	922.523
1993	936.136	936.149	936.174	936.164
1994	954.962	954.974	954.998	954.993
1995	983.328	983.339	983.362	983.362

Table 25 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, Italy, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	407.419	407.419	407.419	407.419
1989	418.924	418.924	418.924	418.924
1990	426.044	426.050	426.064	426.050
1991	433.298	433.304	433.316	433.306
1992	444.833	444.839	444.850	444.844
1993	457.841	457.846	457.857	457.853
1994	471.153	471.158	471.168	471.166
1995	486.941	486.946	486.956	486.956

Table 26 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, Japan, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1829.03	1829.03	1829.03	1829.03
1989	1913.90	1913.90	1913.90	1913.90
1990	2028.71	2028.85	2028.85	2028.76
1991	2151.79	2151.92	2151.92	2151.85
1992	2252.57	2252.69	2252.69	2252.65
1993	2348.16	2348.28	2348.28	2348.25
1994	2497.46	2497.58	2497.58	2497.56
1995	2652.56	2652.67	2652.67	2652.67

Table 27 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, United Kingdom, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	370.824	370.824	370.824	370.824
1989	369.125	369.125	369.125	369.125
1990	364.159	364.167	364.182	364.167
1991	359.541	359.547	359.561	359.550
1992	355.546	355.552	355.564	355.557
1993	353.268	353.274	353.285	353.280
1994	354.639	354.645	354.655	354.653
1995	352.818	352.822	352.831	352.831

Table 28 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, United States, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	2400.04	2400.04	2400.04	2400.04
1989	2444.01	2444.01	2444.01	2444.01
1990	2491.06	2491.07	2491.08	2491.07
1991	2536.93	2536.94	2536.95	2536.94
1992	2579.65	2579.66	2579.67	2579.66
1993	2620.10	2620.11	2620.12	2620.11
1994	2661.16	2661.16	2661.17	2661.17
1995	2704.58	2704.59	2704.59	2704.59

Table 29 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, Other Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	2886.12	2886.12	2886.12	2886.12
1989	2985.50	2985.50	2985.50	2985.50
1990	3090.50	3090.56	3090.68	3090.56
1991	3193.94	3194.00	3194.11	3194.02
1992	3290.73	3290.78	3290.89	3290.83
1993	3389.50	3389.55	3389.65	3389.61
1994	3503.25	3503.29	3503.39	3503.37
1995	3625.00	3625.04	3625.13	3625.14

Table 30 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, market economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	8755.55	8755.55	8755.55	8755.55
1989	9015.79	9015.79	9015.79	9015.79
1990	9303.14	9303.28	9303.57	9303.28
1991	9590.07	9590.20	9590.46	9590.26
1992	9845.83	9845.96	9846.20	9846.06
1993	10105.0	10105.1	10105.4	10105.3
1994	10442.6	10442.7	10443.0	10442.9
1995	10805.2	10805.3	10805.5	10805.5

Table 31 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, Centrally Planned Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	2808.24	2808.24	2808.24	2808.24
1989	2864.63	2864.65	2864.69	2864.65
1990	2921.05	2921.07	2921.11	2921.08
1991	2979.35	2979.37	2979.40	2979.38
1992	3039.53	3039.55	3039.58	3039.57
1993	3100.34	3100.36	3100.39	3100.39
1994	3162.56	3162.58	3162.61	3162.61
1995	3225.50	3225.51	3225.54	3225.54

Table 32 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper consumption, Total World, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	11563.8	11563.8	11563.8	11563.8
1989	11880.4	11880.4	11880.5	11880.4
1990	12224.2	12224.4	12224.7	12224.4
1991	12569.4	12569.6	12569.9	12569.6
1992	12885.4	12885.5	12885.8	12885.6
1993	13205.3	13205.5	13205.7	13205.6
1994	13605.2	13605.3	13605.6	13605.5
1995	14030.7	14030.8	14031.1	14031.1

Table 33 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Canada, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	943.604	943.604	943.604	943.604
1989	968.334	968.309	968.259	968.309
1990	993.702	993.670	993.605	993.661
1991	1021.63	1021.59	1021.51	1021.57
1992	1049.82	1049.77	1049.68	1049.74
1993	1078.94	1078.88	1078.77	1078.83
1994	1108.98	1108.92	1108.79	1108.85
1995	1139.88	1139.81	1139.67	1139.73

Table 34 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Chile, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1348.64	1348.64	1348.64	1348.64
1989	1356.71	1356.69	1356.65	1356.69
1990	1365.01	1365.00	1364.96	1364.99
1991	1372.72	1372.70	1372.67	1372.69
1992	1380.36	1380.34	1380.31	1380.32
1993	1387.77	1387.76	1387.73	1387.74
1994	1395.71	1395.69	1395.67	1395.67
1995	1403.76	1403.75	1403.73	1403.73

Table 35 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Peru, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	420.962	420.962	420.962	420.962
1989	463.925	463.908	463.874	463.908
1990	507.883	507.866	507.833	507.859
1991	519.598	519.583	519.551	519.570
1992	531.170	531.155	531.125	531.137
1993	542.650	542.637	542.609	542.614
1994	554.674	554.662	554.636	554.636
1995	566.734	566.722	566.698	566.698

Table 36 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Philippines, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	494.028	494.028	494.028	494.028
1989	519.851	519.841	519.822	519.841
1990	547.273	547.261	547.239	547.258
1991	575.995	575.982	575.954	575.974
1992	606.384	606.369	606.338	606.356
1993	638.334	638.317	638.281	638.298
1994	672.261	672.241	672.201	672.216
1995	708.193	708.170	708.126	708.142

Table 37 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, South Africa and Namibia, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	276.381	276.382	276.382	276.382
1989	280.459	280.455	280.446	280.455
1990	284.713	284.708	284.698	284.706
1991	289.026	289.021	289.010	289.017
1992	293.411	293.405	293.393	293.400
1993	297.903	297.896	297.883	297.889
1994	302.619	302.612	302.597	302.603
1995	307.467	307.459	307.444	307.446

Table 38 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, United States, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1389.94	1389.94	1389.94	1389.94
1989	1390.60	1390.58	1390.53	1390.58
1990	1391.81	1391.79	1391.74	1391.78
1991	1392.78	1392.75	1392.69	1392.73
1992	1393.84	1393.81	1393.74	1393.78
1993	1394.75	1394.71	1394.65	1394.68
1994	1396.41	1396.37	1396.30	1396.32
1995	1398.20	1398.16	1398.09	1398.11

Table 39 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Zaire, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	503.578	503.578	503.578	503.578
1989	503.904	503.899	503.888	503.899
1990	504.255	504.250	524.240	504.248
1991	504.525	504.521	504.512	504.517
1992	504.779	504.775	504.767	504.770
1993	504.901	504.897	504.890	504.892
1994	505.233	505.230	505.223	505.223
1995	505.512	505.510	505.504	505.503

Table 40 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Zambia, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	567.245	567.245	567.245	567.245
1989	568.050	568.034	568.003	568.034
1990	569.143	569.129	569.101	569.123
1991	569.923	569.909	569.882	569.898
1992	570.690	570.677	570.652	570.663
1993	571.247	571.235	571.210	571.217
1994	572.183	572.171	572.149	572.151
1995	573.117	573.107	573.086	573.088

Table 41 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, other Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1472.97	1472.97	1472.97	1472.97
1989	1530.75	1530.74	1530.70	1530.74
1990	1591.61	1591.59	1591.56	1591.58
1991	1655.09	1655.08	1655.04	1655.06
1992	1721.29	1721.28	1721.24	1721.26
1993	1790.39	1790.38	1790.34	1790.35
1994	1862.83	1862.81	1862.78	1862.78
1995	1938.34	1938.33	1938.29	1938.30

Table 42 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	7417.35	7426.35	7444.35	7426.35
1989	7582.59	7591.45	7609.18	7595.05
1990	7755.41	7764.26	7781.97	7771.41
1991	7901.29	7910.13	7927.82	7920.83
1992	8051.74	8060.58	8078.25	8074.82
1993	8206.89	8215.71	8233.37	8233.51
1994	8370.89	8379.71	8397.35	8397.45
1995	8541.21	8550.02	8567.64	8567.75

Table 43 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Centrally Planned Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	2331.46	2331.46	2331.46	2331.46
1989	2388.63	2388.63	2388.63	2388.63
1990	2445.71	2445.71	2445.71	2445.71
1991	2502.96	2502.96	2502.96	2502.96
1992	2560.41	2560.41	2560.41	2560.41
1993	2617.84	2617.84	2617.84	2617.84
1994	2675.48	2675.48	2675.48	2675.48
1995	2733.11	2733.11	2733.11	2733.11

Table 44 - Base Case and Scenario Projections, 1988 - 1995

Year	Primary copper production, Total World, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	9748.81	9757.81	9775.81	9757.81
1989	9971.22	9980.08	9997.80	9983.68
1990	10201.1	10210.0	10227.7	10217.1
1991	10404.2	10413.1	10430.8	10423.8
1992	10612.2	10621.0	10638.7	10635.2
1993	10824.7	10833.6	10851.2	10851.4
1994	11046.6	11055.2	11072.8	11072.9
1995	11274.3	11283.1	11300.7	11300.9

Table 45 - Base Case and Scenario Projections, 1988 - 1995

Year	Secondary copper production, Federal Republic of Germany, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	185.525	185.525	185.525	185.525
1989	189.347	189.344	189.337	189.344
1990	192.889	192.885	192.878	192.884
1991	196.089	196.085	196.079	196.083
1992	198.342	198.339	198.333	198.336
1993	201.476	201.473	201.468	201.469
1994	205.409	205.407	205.402	205.402
1995	210.966	210.963	210.958	210.958

Table 46 - Base Case and Scenario Projections, 1988 - 1995

Year	Secondary copper production, Japan, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	162.200	162.200	162.200	162.200
1989	169.407	169.404	169.399	169.404
1990	178.838	178.838	178.837	178.836
1991	188.921	188.921	188.922	188.920
1992	197.666	197.666	197.667	197.666
1993	205.863	205.863	205.864	205.863
1994	217.381	217.382	217.383	217.382
1995	229.792	229.793	229.794	229.794

Table 47 - Base Case and Scenario Projections, 1988 - 1995

Year	Secondary copper production, United States, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	484.078	484.078	484.078	484.078
1989	496.635	496.616	496.578	496.616
1990	509.141	509.115	509.063	509.108
1991	521.672	521.644	521.588	521.627
1992	534.017	533.990	533.934	533.963
1993	544.824	544.797	544.743	544.761
1994	555.443	555.417	555.366	555.374
1995	566.350	566.326	566.277	566.280

Table 48 - Base Case and Scenario Projections, 1988 - 1995

Year	Secondary copper production, other Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	461.158	461.158	461.158	461.158
1989	475.826	475.823	475.815	475.823
1990	491.240	491.235	491.224	491.234
1991	507.077	507.071	507.058	507.067
1992	522.819	522.812	511.799	522.807
1993	538.578	538.571	538.557	538.563
1994	555.211	555.204	555.191	555.195
1995	572.868	572.862	572.850	571.852

Table 49 - Base Case and Scenario Projections, 1988 - 1995

Year	Secondary copper production, Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1292.96	1292.96	1292.96	1292.96
1989	1331.21	1331.19	1331.13	1331.19
1990	1372.11	1372.07	1372.00	1372.06
1991	1413.76	1413.72	1413.65	1413.70
1992	1452.84	1452.81	1452.73	1452.77
1993	1490.74	1490.70	1490.63	1490.66
1994	1533.45	1533.41	1533.34	1533.35
1995	1579.98	1579.94	1579.88	1579.88

Table 50 - Base Case and Scenario Projections, 1988 - 1995

Year	Refined copper stocks in private hands, Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	1268.81	1268.81	1268.81	1268.81
1989	1314.62	1314.72	1314.94	1314.72
1990	1340.43	1340.57	1340.85	1340.61
1991	1377.48	1377.64	1377.94	1377.73
1992	1408.13	1408.29	1408.60	1408.44
1993	1437.44	1437.60	1437.92	1437.82
1994	1472.06	1472.22	1472.53	1472.49
1995	1511.70	1511.85	1512.17	1512.15

Table 51 - Base Case and Scenario Projections, 1988 - 1995

Year	Copper mine production capacity, Market Economies, in 1000 tons			
	Base case	Scenario 1	Scenario 2	Scenario 3
1988	9104.20	9113.20	9131.20	9113.20
1989	9364.48	9373.46	9391.40	9377.06
1990	9638.47	9647.42	9665.32	9654.61
1991	9897.63	9906.56	9924.41	9917.33
1992	10172.4	10181.3	10199.1	10195.6
1993	10463.5	10472.4	10490.1	10490.3
1994	10772.4	10781.3	10799.0	10799.1
1995	11100.0	11108.8	11126.5	11126.7

IV SUMMARY OF FINDINGS

Our base case forecasting results suggest that the present state of the copper market will not change substantially in the near future. Unless significant new exogenous developments will take place, as, for instance, a strong growth in the industrial activity of the main copper users, real copper prices will increase only slowly and will remain below $ 1.10 per Pound (in 1982 US-Dollar). However, this pattern could be influenced by adjustments on the supply side, in response to the last decade of weak prices, by closing down inefficient mines.

Although it is questionable whether copper mining from deep-sea nodules will actually take place already in the late 1980s, an examination of the effects of ocean mining is nevertheless a meaningful exercise, because the qualitative reactions of the world copper industry will remain the same, by and large, as long as the structure of market does not change substantially. However, increasing government interventions in the mining industries, oligopolistic producer collusion, possibly combined with changing expectations formation processes of the market participants, could very well lead to structural changes in the world copper industry which would prohibit a further application of the model in its current form.

Under the assumption that such structural breaks will not occur, simulation exercises based on three scenarios, differing in their assumptions regarding the amount of copper produced from manganese nodules, were performed. All three scenarios assume that only a very small output of copper will be mined from manganese nodules: only between 0.0931 % (in Scenario 1, "low") and 0.2793 % (Scenario 2, "high") of the world's refined copper production in 1981. Therefore it is not surprising that the detailed presentation of our results in tables and figures showed that the actual effects of copper production from manganese nodules in a range suggested by the three scenarios are practically almost neglegible. However, the consideration of the deviations from the base forecast due to copper production from nodules mining nevertheless allowed some interesting conclusions about the relative effects of copper production from manganese nodules.

Summing up the most important results of our simulation experiments we can record the following points:

1. The absolute effects of copper production from manganese nodules, beginning in 1988, on land-based production, consumption and prices of copper are very small, almost ~~certainly~~ smaller than ubiquitous measurement errors in copper statistics. This relative insignificance of ocean mine production for the world copper industry follows from our assumptions about the amount of copper extracted from manganese nodules, which is less than three tenth of a percent in terms of the projected primary and secondary production in the 1980s and 1990s.

2. The relative effects of copper production from manganese nodules are:

   a) depressed prices, which increase again slowly after a constant level of offshore production has begun, and

   b) corresponding increases in copper consumption,

   c) only very slight decreases in copper mine production and capacities, which are somewhat more pronounced in the industrialized copper producing countries, and consequently

   d) increased private copper inventories.

It is to be expected that the conclusions in regard to the relative effects of copper production from ocean floor nodules hold also in the case of higher copper recovery rates.

Furthermore, it has been shown that the copper market is able to absorb the minor supply shock resulting from ocean mining. Thus, the impact of seabed mining on the world copper market can be expected to be marginal.

On the other hand, additional copper availability at lower prices should enhance competition on the supply side and probably act as a catalysator for structural adjustment, which can be said to have been avoided much too long, considering the comparatively low level of real prices experienced in the post-war period.

REFERENCES

A d a m s, F. G. [1973] "The Impact of Copper Production from the Ocean Floor". Study prepared for UNCTAD. Philadelphia: Economics Research Unit, University of Pennsylvania.

--, [1975] "Applied Econometric Modeling of Non-Ferrous Metal Markets. The Case of Ocean Floor Nodules." In W. A. Vogely (ed.): Mineral Materials Modeling. A State-of-the Art Review. Washington: Resources for the Future, pp. 133 - 149.

--, [1980] "The Law of the Sea Treaty and the Regulation of Nodule Exploitation." Journal of Policy Modeling, Vol. 2, pp. 19 - 33.

A m a c h e r, R. C., S w e e n y, R. J. [1976] "International Commodity Cartels and the Threat of New Entry: Implications of Ocean Mineral Resources." Kyklos, 29, pp. 292 - 309.

B e h r m a n, J. R. [1970] "Forecasting Properties and Prototype Simulations of a model of the Copper Market". Report prepared for the General Services Administration, Philadelphia. Economics Research Unit, University of Pennsylvania.

B u r l e y, S. P. [1974] "Short Term Variations in Copper Prices." Research Memorandum No. 82, Wien, Institut für Höhere Studien und Wissenschaftliche Forschung.

C h e m i c a l B a n k [1981] "Copper, the Next Twenty Years". New York.

C o p p e r D e v e l o p m e n t A s s o c i a t i o n, I n c., Copper Annual Data, New York.

D a t a R e s o u r c e s, I n c. [1983], European Long-Term Review. August/September 1983, Lexington, Mass.

G i l b e r t, C. L. [1982] "Some Problems in Testing the Efficient Market Hypothesis of Foreign Reserve and Commodity Market Data". Oxford, Institute of Economics and Statistics, University of Oxford, mimeo, October 1982.

G l u s c h k e, W., S h a w, J., V a r o n, B. [1979] Copper. The Next Fifteen Years. Dordrecht, D. Reidel Publishing Company.

G o e l l e r, H. E., W e i n b e r g, A. V. [1978] "The Age of Substitutability." American Economic Review, 68, pp. 1 - 11.

G u p t a, S., M a y e r, T. [1981] "A Test of the Efficiency of Future Markets in Commodities." Weltwirtschaftliches Archiv, 117, pp. 661 - 671.

G o s s, B. A. [1981] "The Forward Pricing Function of the London Metal Exchange." Applied Economics, 13, pp. 133 - 150.

H o j m a n, D. E. [1980] "International Trade in Copper: Static and Dynamic Aspects of the Instability Problem and the Commodity Agreement Solution." In A. Sengupta (ed.): Commodities, Finance and Trade: Issues in North-South Negotiations. London, Frances Pinter.

H w a, E. C. [1979] "Price Determination in Several International Primary Commodity Markets: A Structural Analysis." International Monetary Fund Staff Papers, 26, pp. 157 - 188.

L a b y s W. C. [1982] "The Role of State Trading in Mineral Commodity Markets." In M. M. Kostecki (ed.): State Trading in International Markets, New York, St. Martin's Press, pp. 78 - 102.

M a r i a n o, R. S. [1978] "Commodity Market Modeling: Methodological Issues and Control Theory Applications." In F. G. Adams and J. R. Behrman (eds.): Econometric Modeling of World Commodity Policy. Lexington, Mass., D. C. Heath and Company.

M ü l l e r - O h l s e n, Lotte, Die Weltmetallwirtschaft im industriellen Entwicklungsprozeß, Kieler Studie Nr. 165, Tübingen [1981].

M c N i c o l, D. L. [1975] "The Two-Tier Price System in the Copper Industry." Bell Journal of Economics, 6, pp. 50 - 73.

M i k e s e l l, R. F. [1979], The World Copper Industry. Structure and Economic Analysis. Baltimore, Johns Hopkins University Press.

P e t r i c k, A., B e n n e t t, H. J., S t a r c h, K. E., W e i s n e r, R. C. [1973] "The Economics of Byproduct Metals, 1. Copper System." Information Circular 8569, Washington, US Bureau of Mines.

R a d e t z k i, M. [1977] "Will the Long-Run Global Supply of Industrial Metal Minerals be Adequate?" Seminar Paper No. 85, Stockholm, Institute for International Economic Studies, University of Stockholm.

--, [1981] "Has Political Risk Scared Mineral Investments Away from the Deposits in Developing Countries?" Seminar Paper No. 169, Stockholm, Institute for International Economic Studies, University of Stockholm.

R a d e t z k i, M. [1983] "Long-Run Price Prospects for Aluminum and Copper." Natural Resources Forum, 7, pp. 23 - 36.

S c h r o e d e r, H. J. [1979] "Copper", Mineral Commodity Profile, Washington, US Bureau of Mines.

T i l t o n, J. E. [1977], The Future of Nonfuel Minerals. Washington, The Brookings Institution.

U n i t e d N a t i o n s [1981], Transnational Corporations in the Copper Industry. New York, Centre on Transnational Corporations.

W a g e n h a l s, G. [1981] "Private Storage and Public Buffer Stocks. Some Preliminary Thoughts." Working Paper, Philadelphia, Economics Research Uniy, University of Pennsylvania.

--, [1983a] "The World Copper Market: Structure and Econometric Model." Alfred Weber-Institut, University of Heidelberg, mimeo, June 1983.

--, [1983b] "Ökonometrische Modelle für NE-Metallmärkte." Metall, 37 (5), pp. 514 - 519.

--, [1984a] "Econometric Model of Minerals and Metal Markets." Natural Resources Forum, forthcoming.

--, [1984b] "New Developments in Econometric Commodity Market Modeling: A Model of the World Copper Market." In P. Thoft-Christensen (ed.) System Modelling and Optimization, Proceedings of the 11th IFIP Conference, Copenhagen, Denmark, July 25 - 29, 1983, New York, Berlin, Heidelberg, Springer Verlag.

W o r l d B a n k [1982], Price Prospects for Major Primary Commodities, Volume IV, Washington, D. C.

--, [1983a] "The Outlook for Primary Commodities." World Bank Staff Commodity Working Paper, Number 9, January 1983, Washington, D. C.

--, [1983b], Price Prospects for Major Primary Commodities, Washington, D. C.

Z e l l n e r, A. [1962] "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias." Journal of the American Statistical Association, 57, pp. 348 - 368.

APPENDIX A: Data Sources and Model Symbols

Data Sources

CDA	Copper Supply and Consumption, Copper Development Association
FP	Metal Statistics, Fairchild Publications
IMF	International Financial Statistics, International Monetary Fund
NG	Metal Statistics, Metallgesellschaft AG
PD	Phelps Dodge Co.
TR	Transformation (Construction of variables is described in Wagenhals [1983a, Appendix I])
UN	Monthly Bulletin of Statistics and Statistical Yearbook, United Nations
WBMS	World Metal Statistics, World Bureau of Metal Statistics
WEFA	Wharton Econometric Forecasting Associates
WB	Commodity Trade and Price Trends, World Bank
WB79	World Bank [1979]

Model Symbols

Variable	Description	Source
BSRW	Balancing surplus, not reported as stocks, outside the United States	TR
BSUS	Balancing surplus, not reported as stocks, United States	TR
COSTCA	Unit cost of mining index, Canada, 1975 = 1.00	TR

Variable	Description	Source
COSTCH	Unit cost of mining index, Chile, 1975 = 1.00	TR
COSTPE	Unit cost of mining index, Peru, 1975 = 1.00	TR
COSTPH	Unit cost of mining index, Philippines, 1975 = 1.00	TR
COSTSA	Unit cost of mining index, South Africa and Namibia, 1975 = 1.00	TR
COSTUS	Unit cost of mining index, United States, 1975 = 1.00	TR
COSTZI	Unit cost of mining index, Zaire, 1975 = 1.00	TR
COSTZM	Unit cost of mining index, Zambia, 1975 = 1.00	TR
DCH	Dummy variable for Chile before the nationalization of the Gran Minera: 1 in 1954 - 1969, 0 otherwise	-
D..	Dummy vaiable: 1 in 19.., 0 otherwise, (e. g.: D59 is 1 in 1959 and 0 otherwise)	-
DEX	Dummy variable for US copper export and price controls: 1 in 1965 - 1970 and 1973 - 1975, 0 otherwise	-
DPE	Dummy variable for Peru beginning with the expropriation of the Cerro Corporation properties by Centromin: 1 for 1974 - 1980, 0 otherwise	-
DSPEC	Dummy variable for the excessive speculation during the commodity boom 1972/73 and against the Pound sterling in 1978/1979: 1 in 1972/73 and 1979, 0 otherwise	-
DST	Dummy variable for strike induced changes in copper stocks: -.5 in 1954, 1968, 1971, -1 in 1967	-
DSTCA	Dummy variable for major strikes in the Canadian copper industry: .5 in 1966, 1969, 1978, 1 in 1979, 0 otherwise	-

Variable	Description	Source
DSTUS	Dummy variable for major strikes in the US copper industry: .5 in 1959, 1968, 1975, 1979/80, 1 in 1967	-
DZI	Dummy variable for production cut-backs during the Katanga war and the disorders after it: 1 in 1963 - 1965, 0 otherwise	-
EUVI	Index of export unit values, industrialized countries, 1975 = 1.00	IMF
IIPEW	Index of industrial production, centrally planned economies, 1975 = 100	UN
IIPGE	Index of industrial production, Federal Republic of Germany, 1975 = 100	IMF
IIPIT	Index of industrial production, Italy, 1975 = 100	IMF
IIPJA	Index of industrial production, Japan, 1975 = 100	IMF
IIPUK	Index of industrial production, United Kingdom, 1975 = 100	IMF
IIPUS	Index of industrial production, United States, 1975 = 100	IMF
IIPWW	Index of industrial production, Market Economies, 1975 = 100	IMF
INTEU	Eurodollar rate in London (LIBOR)	IMF
INTGE	Discount rate, end of period, Federal Republic of Germany	IMF
INTUK	Bank rate, United Kingdom, deflated with UK price index of industrial production	IMF
PALLME	Average annual price of aluminum, 99.5 % ingot, London, lb. per ton	MG

Variable	Description	Source
PALUS	Average annual price of aluminum, 99.5 % ingots, New York, US $ per ton	MG
PAU	Average annual price of gold, $ per fine ounce	IMF
PCIF	International price index, unit values of manufactures (SITC 5 - 8), 1975 = 100	WB
PCUCA	Average annual price of copper, electrolytic copper, wirebars, Canadian producers, Canadian cents per lb.	FP
PCUCH	Average annual price of copper, electrolytic copper, wirebars, Chile (cif), US $ per ton	MG WB79
PCULME	Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, cash, Pound sterling per ton	MG
PCULMEF	Average annual price of copper, electrolytic copper, wirebars, London Metal Exchange, future, Pound sterling per ton	MG
PCUUS	Average annual price of copper, electrolytic copper, wirebars, US producers (fob refinery), US $ per ton	MG
PSUS	Average annual price of dealers' No. 2 heavy copper scrap, US $ per ton	MG
PWIGE	Price index of industrial output, Federal Republic of Germany, 1975 = 1.00	IMF
PWIIT	Wholesale price index, general, Italy, 1975 = 1.00	IMF
PWIJA	Wholesale price index, general, Japan, 1975 = 1.00	IMF
PWIUK	Price index of industrial output, United Kingdom, 1975 = 1.00	IMF

Variable	Description	Source
PWIUS	Wholesale price index, general, United States, 1975 = 1.00	IMF
QCGE	Total copper consumption, Federal Republic of Germany, in 1000 tons	MG
QCIT	Total copper consumption, Italy, in 1000 tons	MG
QCJA	Total copper consumption, Japan, in 1000 tons	MG
QCOM	Total copper consumption, other Market Economies, in 1000 tons	MG
QCREW	Refined copper consumption, centrally planned economies, in 1000 tons	MG
QCRGE	Refined copper consumption, Federal Republic of Germany, in 1000 tons	MG
QCRIT	Refined copper consumption, Italy, in 1000 tons	MG
QCRJA	Refined copper consumption, Japan, in 1000 tons	MG
QCROM	Refined copper consumption, other Market Economies, in 1000 tons	MG
QCRTW	Refined copper consumption, total world, in 1000 tons	MG
QCRUK	Refined copper consumption, United Kingdom, in 1000 tons	MG
QCRUS	Refined copper consumption, United States, in 1000 tons	MG

Variable	Description	Source
QCRWW	Refined copper consumption, Market Economies in 1000 tons	MG
QCUK	Total copper consumption, United Kingdom, in 1000 tons	MG
QCUS	Total copper consumption, United States, in 1000 tons	MG
QCWW	Total copper consumption, Market Economies, in 1000 tons	MG
QIMRUS	Net imports of refined copper, United States, in 1000 tons	CDA
QIMUS	Net imports of copper, United States, in 1000 tons	CDA
QIMWW	Net imports of refined copper from Centrally Planned Economies to Market Economies	WBMS
QMCA	Copper mine production, Canada, in 1000 tons	MG
QMCAC	Copper mine production capacity, Canada, in 1000 tons	PD
QMCH	Copper mine production, Chile, in 1000 tons	MG
QMCHC	Copper mine production capacity, Chile, in 1000 tons	PD
QMEW	Copper mine production, Centrally Planned Economies, in 1000 tons	MG
QMOM	Copper mine production, other Market Economies, in 1000 tons	MG

Variable	Description	Source
QMOMC	Copper mine production capacity, other Market Economies, in 1000 tons	PD
QMPE	Copper mine production, Peru, in 1000 tons	MG
QMPEC	Copper mine production capacity, Peru, in 1000 tons	PD
QMPH	Copper mine production, Philippines, in 1000 tons	MG
QMPHC	Copper mine production capacity, Philippines, in 1000 tons	PD
QMSA	Copper mine production, South Africa and Namibia, in 1000 tons	MG
QMSAC	Copper mine production capacity, South Africa and Namibia, in 1000 tons	PD
QMTW	Copper mine production, total world, in 1000 tons	MG
QMUS	Copper mine production, United States, in 1000 tons	MG
QMUSC	Copper mine production capacity, United States, in 1000 tons	PD
QMWW	Copper mine production, Market Economies, in 1000 tons	MG
QMWWC	Copper mine production capacity, Market Economies, in 1000 tons	PD
QMZI	Copper mine production, Zaire, in 1000 tons	MG

Variable	Description	Source
QMZIC	Copper mine production capacity, Zaire, in 1000 tons	PD
QMZM	Copper mine production, Zambia, in 1000 tons	MG
QMZMC	Copper mine production capacity, Zambia, in 1000 tons	PD
QRUS	Refined copper production, United States, in 1000 tons	MG
QSGE	Production of refined copper from scrap, Federal Republic of Germany, in 1000 tons	MG
QSJA	Production of refined copper from scrap, Japan, in 1000 tons	MG
QSOM	Production of refined copper from scrap, other Market Economies, in 1000 tons	MG
QSUS	Production of refined copper from scrap, United States, in 1000 tons	MG
QSWW	Production of refined copper from scrap, Market Economies, in 1000 tons	MG
REXCA	Exchange rate, Canadian Dollars, per US-Dollar	IMF
REXCH	Exchange rate, Chilean Pesos per US-Dollar	IMF
REXGE	Exchange rate, Deutsche Mark per US-Dollar	IMF
REXIT	Exchange rate, Italian Lire per US-Dollar	IMF
REXJA	Exchange rate, Japanese Yen per US-Dollar	IMF
REXPE	Exchange rate, Peruvian Soles per US-Dollar	IMF

Variable	Description	Source
REXPH	Exchange rate, Philippine Pesos per US-Dollar	IMF
REXSA	Exchange rate, South African Rand per US-Dollar	IMF
REXUK	Exchange rate, Pound sterling per US-Dollar	IMF
REXZI	Exchange rate, Zaires per US-Dollar	IMF
REXZM	Exchange rate, Zambian Kwacha per US-Dollar	IMF
STGE	Refined copper stocks, Federal Republic of Germany, in 1000 tons	WBMS
STGUS	Refined copper stocks, strategic stockpile, United States,	SBMS
STJA	Refined copper stocks, Japan, in 1000 tons	WBMS
STLME	Refined copper stocks, London Metal Exchange, in 1000 tons	WBMS
STOM	Refined copper stocks, other Market Economies, in 1000 tons	WBMS
STUS	Refined copper stocks, United States, in 1000 tons	WBMS
STWW	Refined copper stocks, Market Economies, in 1000 tons	WBMS
T	Time trend, 1963 = 100, increasing (decreasing) by 1 each succeeding (preceding) year	-
UCCA	User cost of capital index, mining, Canada, 1975 = 100	TR
UCCH	User cost of capital index, mining, Chile, 1975 = 100	TR

Variable	Description	Source
UCOM	User cost of capital index, mining, other Market Economies, 1975 = 100	TR
UCPE	User cost of capital index, mining, Peru, 1975 = 100	TR
UCPH	User cost of capital index, mining, Philippines, 1975 = 100	TR
UCSA	User cost of capital index, mining, South Africa and Namibia, 1975 = 100	TR
UCUS	User cost of capital index, mining, United States, 1975 = 100	TR
UCZI	User cost of capital index, mining, Zaire, 1975 = 100	TR
UCZM	User cost of capital index, mining, Zambia, 1975 = 100	TR

APPENDIX B: The Complete Model

General Remarks

The estimation of the following equations is based on annual data from 1955 to 1980. The figures in parentheses denote the t-statistics, $\bar{R}^2$ is the adjusted coefficient of determination, and DW means Durbin-Watson coefficient.

In the consumption equations no $\bar{R}^2$ is presented, because these equations were estimated with Zellner's method of seemingly unrelated regressions [Zellner, 1962]. This method was used to account for simultaneous business cycle movements in the most important copper-using countries. The remaining equations were estimated either with the ordinary least squares method, or with the Cochrane-Orcutt procedure, if autororrelation was detected with the Durbin-Watson test or with Geary's test. In the latter case, we also present the estimates of the first order coefficients of autocorrelation. Single equation estimation methods were chosen, because they generally are more robust against omnipresent specification errors than the simultaneous equation methods [Mariano, 1978, pp. 81 - 84].

On the following pages, we list the detailed estimation results for each equation and we present the identities closing the model.

Demand

Total Consumption

Federal Republic of Germany

$$\log(QCGE) = \underset{(7.35)}{2.71} - \underset{(-2.75)}{.0814} \log((PCULME_{-1} \cdot REXGE_{-1}) / (REXUK_{-1} \cdot PWIGE)_{-1}) + \underset{(3.67)}{.278} \log((PALLME_{-1} \cdot REXGE_{-1}) / (REXUK_{-1} \cdot PWIGE_{-1})) + \underset{(19.8)}{.748} \log(IIPGE),$$

DW = 1.80.

Italy

$$\log(QCIT) = \underset{(1.57)}{1.50} - \underset{(-2.26)}{.076} \log((PCULME_{-1} \cdot REXIT_{-1}) / (REXUK_{-1} \cdot PWIIT)_{-1}) + \underset{(1.45)}{.140} \log((PALLME_{-1} \cdot REXIT_{-1}) / (REXUK_{-1} \cdot PWIIT_{-1})) + \underset{(34.9)}{.892} \log(IIPIT),$$

DW = 1.70.

Japan

$$\log(QCJA) = \underset{(2.19)}{1.77} - \underset{(-2.49)}{.0972} \log((PCULME_{-1} \cdot REXJA_{-1}) / (REXUK_{-1} \cdot PWIJA)_{-1}) + \underset{(2.94)}{.305} \log((PALLME_{-1} \cdot REXJA_{-1}) / (REXUK_{-1} \cdot PWIJA_{-1})) + \underset{(48.0)}{.826} \log(IIPJA),$$

DW = 1.94.

United Kingdom

$$\log(QCUK) = \underset{(1.85)}{1.08} - \underset{(-3.16)}{.0954} \log(PCULME_{-1} / PWIUK_{-1}) + \underset{(9.51)}{1.37} \log(IIPUK) - \underset{(-10.8)}{.0357} T,$$

DW = 1.17.

United States

$$\log(QCUS) = \underset{(7.84)}{5.58} - \underset{(-.308)}{.0346} \log(PCUUS_{-1} / PWIUS_{-1}) + \underset{(.583)}{.129} \log(PALUS_{-1} / PWIUS_{-1}) + \underset{(8.02)}{.461} \log(IIPUS) + \underset{(2.46)}{.203} D66$$

DW = 1.45.

Other Market Economies

$$\log(QCOM) = \underset{(13.1)}{3.54} - \underset{(-2.92)}{.0851} \log((PCULME_{-1} / (REXUK_{-1} \cdot PCIF_{-1})) + \underset{(1.67)}{.129} \log((PALLME_{-1} / (REXUK_{-1} \cdot PCIF_{-1})) + \underset{(30.1)}{.912} \log(IIPWW),$$

DW = 1.29.

Refined Consumption

Federal Republic of Germany

$$QCRGE = \underset{(-.652)}{-21.0} + \underset{(19.3)}{.826} QCGE,$$

DW = 1.79

Italy

QCRIT = 30.2 + .565 QCIT,
(4.88) (36.0)

DW = 1.10.

Japan

QCRJA = -98.8 + .808 QCJA,
(-10.2) (89.0)

DW = .941.

United Kingdom

QCRUK = 4.04 + .779 QCUK,
(.143) (18.6)

DW = 1.42.

United States

QCRUS = -24
8 + .779 QCUS,
(-6.4) (51.4)

DW = 1.52.

Other Market Economies

QCROM = -109 + .822 QCOM,
(-3.7) (57.7)

DW = 1.47.

Centrally Planned Economies

$$\log(QCREW) = \underset{(34.4)}{4.59} - \underset{(-.643)}{.0155} \log(PCULME_{-1} / (REXUK_{-1} \cdot PCIF)_{-1}) + \underset{(25.1)}{.661} \log(IIPEW),$$

Estimate of first-order autocorrelation coefficient:

$$RHO = \underset{(4.03)}{.628},$$

$$\bar{R}^2 = .963, \qquad DW = 2.04.$$

Demand for Storage

Federal Republic of Germany

$$STGE = \underset{(.238)}{1.96} + \underset{(1.78)}{.277} STGE_{-1} - \underset{(-1.00)}{2.01} INTGE + \underset{(1.74)}{.0325} (PCULMEF - PCULME) \cdot REXGE / REXUK + \underset{(3.43)}{.695} IIPGE + \underset{(3.74)}{43.9} D77,$$

$$\bar{R}^2 = .888, \qquad DW = 2.00.$$

Japan

$$STJA = \underset{(-.0014)}{-.0216} + \underset{(3.80)}{.586} STJA_{-1} + \underset{(1.64)}{.0012} (PCULMEF - PCULME) \cdot REXJA / REXUK + \underset{(2.05)}{.621} IIPJA + \underset{(1.44)}{59.0} D77,$$

$$\bar{R}^2 = -862, \qquad DW = 1.57.$$

<u>London Metal Exchange</u>

$$STLME = \underset{(-.0241)}{-.678} + \underset{(5.18)}{.353}\, STLME_{-1} - \underset{(-2.75)}{5.35}\, INTUK + \underset{(2.31)}{1.38}\, (PCULMEF - PCULME) + \underset{(1.88)}{.728}\, IIPWW + \underset{(7.90)}{278}\, (D75 + D76 + D77),$$

$$\bar{R}^2 = .969, \qquad DW = 2.54.$$

<u>United States</u>

$$STUS = \underset{(5.99)}{273} + \underset{(2.37)}{.232}\, STUS_{-1} - \underset{(-2.80)}{17.3}\, INTEU + \underset{(1.87)}{.533}\, (PCULMEF - PCULME) / REXUK - \underset{(-2.80)}{.139}\, STGUS + \underset{(2.46)}{1.22}\, EUVI - \underset{(-3.78)}{87.4}\, DSPEC + \underset{(7.73)}{117.6}\, DST,$$

$$\bar{R}^2 = .939, \qquad DW = 2.53.$$

<u>Other Market Economies</u>

$$STOM = \underset{(-.575)}{-9.39} + \underset{(8.26)}{.734}\, STOM_{-1} + \underset{(.528)}{.936}\, (PCULMEF - PCULME) / REXUK + \underset{(1.76)}{.556}\, IIPWW + \underset{(8.54)}{216}\, D75$$

$$\bar{R}^2 = .961, \qquad DW = 2.59.$$

Supply

Primary Supply

<u>Canada</u>

$$\log(QMCA) = \underset{(-1.68)}{-.394} + \underset{(31.6)}{.894} \log(QMCAC) + \underset{(3.72)}{.225} \log(PCUCA / COSTCA) - \underset{(-4.79)}{.175} DSTCA,$$

$$\bar{R}^2 = .983, \qquad DW = 1.29.$$

<u>Chile</u>

$$\log(QMCH) = \underset{(-3.62)}{0.17} + \underset{(23.8)}{1.145} \log(QMCHC) + \underset{(3.72)}{.0682} \log(PCUCH \cdot REXCH / COSTCH),$$

$$\bar{R}^2 = .961, \qquad DW = 1,58.$$

<u>Peru</u>

$$\log(QMPE) = \underset{(-3.17)}{-2.86} + \underset{(27.1)}{1.15} \log(QMPEC) + \underset{(2.40)}{.167} \log((PCULME \cdot REXPE) / (REXUK \cdot COSTPE)),$$

$$\bar{R}^2 = .970, \qquad DW = 1.78.$$

<u>Philippines</u>

$$\log(QMPH) = \underset{(-1.67)}{-.464} + \underset{(71.2)}{.953} \log(QMPHC) + \underset{(2.37)}{.0657} \log((PCULME \cdot REXPH) / (REXUK \cdot COSTPH)),$$

$$\bar{R}^2 = .995, \qquad DW = 1.69.$$

South Africa and Namibia

$$\log(QMSA) = \underset{(-.845)}{-.298} + \underset{(36.2)}{.983}\log(QMSAC) + \underset{(1.13)}{.0506}\log((PCULME \cdot REXSA) / (REXUK \cdot COSTSA)),$$

$$\bar{R}^2 = .981, \qquad DW = 1.59.$$

United States

$$\log(QMUS) = \underset{(1.38)}{-.693} + \underset{(22.4)}{873}\log(QMUSC) + \underset{(3.90)}{.202}\log(PCUUS / COSTUS) - \underset{(-14.2)}{.438}\, DSTUS,$$

$$\bar{R}^2 = .96, \qquad DW = 1.90.$$

Zaire

$$\log(QMZI) = \underset{(1.39)}{.320} + \underset{(33.4)}{.868}\log(QMZIC) - \underset{(-6.97)}{.149}\, DZI + \underset{(3.12)}{.0562}\log((PCULME \cdot REXZI) / (REXUK \cdot COSTTI)),$$

$$\bar{R}^2 = .981, \qquad DW = 2.49.$$

Zambia

$$\log(QMZM) = \underset{(-.502)}{-.234} + \underset{(15.3)}{.908}\log(QMZMC) + \underset{(3.44)}{.103}\log((PCULME \cdot REXZM) / (REXUK \cdot COSTZM)),$$

$$\bar{R}^2 = .904, \qquad DW = 1.80.$$

Other Market Economies

$$\log(QMOM) = \underset{(3.29)}{2.36} + \underset{(6.21)}{.620} \log(QMOMC) + \underset{(1.27)}{.0490} \log(PCULME / (REXUK . PCIF)),$$

Estimate of first-order autocorrelation coefficient:

$$RHO = \underset{(8.76)}{.869},$$

$$\bar{R}^2 = .607, \qquad DW\ 0\ 1.47.$$

Centrally Planned Economies

$$\log(QMEW) = \underset{(22.2)}{4.48} + \underset{(2.78)}{.681} \log(T) + \underset{(.817)}{.167} \log(IIPEW),$$

Estimate of first-order autocorrelation coefficient:

$$RHO = \underset{(4.11)}{.635},$$

$$\bar{R}^2 = .967, \qquad DW = 1.98.$$

Mine Production Capacity

Canada

$$QMCAC = \underset{(0.23)}{4.71} + \underset{(26.1)}{.901} QMCAC_{-1} + \underset{(3.46)}{.178} (PCUCA . QMCA / UCCA),$$

$$\bar{R}^2 = .980, \qquad DW = 1.74.$$

Chile

$$QMCHC = \underset{(1.31)}{114} + \underset{(10.6)}{.887} QMCHC_{-1} + \underset{(.521)}{.00144} (PCUCH . QMCH / UCCH) - \underset{(-1.51)}{45.9} DCH,$$

$$\bar{R}^2 = .951, \qquad DW = 2.48.$$

Peru

QMPEC $= \underset{(.926)}{23.0} + \underset{(7.95)}{.808}\ QMPEC_{-1} + \underset{(1.05)}{.000374}\ (PCULME$

$.\ QMPE\ .\ REXPE\ /\ (REXUK\ .\ UCPE)) + \underset{(2.32)}{58.4}\ DPE,$

$\overline{R}^2 = .871, \qquad DW = 2.44.$

Philippines

QMPHC $= \underset{(-.566)}{-.329} + \underset{(39.0)}{1.03}\ QMPHC_{-1} + \underset{(1.61)}{.000474}\ ((PCULME$

$.\ QMPH\ .\ REXPH\ /\ (REXUK\ .\ UCPH),$

$\overline{R}^2 = .988, \qquad DW = 1.51.$

South Africa and Namibia

QMSAC $= \underset{(-.168)}{-1.00} + \underset{(30.3)}{1.00}\ QMSAC_{-1} + \underset{(.984)}{.00243}\ (PCULME\ .$

$QMSA\ .\ REXSA\ /\ (REXUK\ .\ UCSA)) + \underset{(5.39)}{68{,}5}\ D66,$

$\overline{R}^2 = .979, \qquad DW = 1.88.$

United States

QMUSC $= \underset{(.920)}{31.3} + \underset{(47.9)}{.921}\ QMUSC_{-1} + \underset{(3.90)}{.00525}\ PCUUS\ .\ QMUS$

$/\ UCUS + \underset{(4.17)}{123}\ D67 + \underset{(5.41)}{109}\ (D75 - D76),$

$\overline{R}^2 = .990, \qquad DW = 2.36.$

Zaire

QMZIC $= \underset{(-.319)}{-6.23} + \underset{(26.0)}{.995}\ QMZIC_{-1} + \underset{(1.94)}{.00526}\ (PCULME\ .$

$QMZI\ .\ REXZI\ /\ (REXUK\ .\ UCZI)) - \underset{(-2.03)}{45.5}\ D78,$

$\bar{R}^2 = .966, \qquad DW = 1.24$

Zambia

QMZMC $= \underset{(2.54)}{59.1} + \underset{(29.2)}{.919}\ QMZMC_{-1} + \underset{(.802)}{.000810}\ (PCULME\ .$

$QMZM\ .\ REXZM\ /\ (REXUK\ .\ UCZM)),$

$\bar{R}^2 = .971, \qquad DW = 1.79.$

Other Market Oconomies

QMOMC $= \underset{(-.351)}{-18.4} + \underset{(24.0)}{1.07}\ QMOMC_{-1} + \underset{(.317)}{.000764}\ (PCULME$

$.\ QMOM)\ /\ (REXUK\ .\ UCOM),$

$\bar{R}^2 = .958, \qquad DW = 1.47.$

Refined Copper Supply

United States

QRUS $= \underset{(16.7)}{1025} + \underset{(8.72)}{.432}\ QMUS - \underset{(-6.14)}{1192}\ STUS\ /\ QCUS$

$- \underset{(8.56)}{319}\ DSTUS,$

$\bar{R}^2 = .906, \qquad DW = 1.57.$

Secondary Supply

Federal Republic of Germany

QSGE $= \underset{(1.42)}{30.4} + \underset{(1.24)}{.219}\ QSGE_{-1} + \underset{(2.25)}{.439}\ ((PCULME$

$. REXGE) / (REXUK . PWIGE)) + \underset{(3.95)}{.804}\ IIPGE,$

$\bar{R}^2 = .682, \qquad DW = 2.09.$

Japan

QSJA $= \underset{(-.608)}{-5.32} + \underset{(1.68)}{.210}\ QSJA_{-1} + \underset{(2.95)}{.00365}\ ((PCULME$

$. REXGE) / (REXUK . PWIGE)) + \underset{(6.12)}{.515}\ QCJA,$

$\bar{R}^2 = .884, \qquad DW = 1.65.$

United States

QSUS $= \underset{(-.727)}{-24.8} + \underset{(4.23)}{.383}\ QSUS_{-1} + \underset{(3.26)}{8.30}\ PSUS / PWIUS$

$- \underset{(-3.65)}{505}\ STUS / QCUS + \underset{(6.81)}{2.32}\ IIPUS - \underset{(-1.37)}{41.1}\ D67,$

$\bar{R}^2 = .927, \qquad DW = 2.24.$

Other Market Economies

QSOM $= \underset{(.523)}{12.0} + \underset{(4.13)}{.623}\ QSOM_{-1} + \underset{(1.60)}{1.21}\ (PCULME / REXUK$

$. PCIF)) + \underset{(2.25)}{1.04}\ IIPWW$

$\bar{R} = .910, \qquad DW = 1.53.$

Other Equations

Prices

<u>Canada</u>

PCUCA $= \underset{(-4.67)}{-10.1} + \underset{(6.74)}{.0171}$ (PCULME . REXCA / REXUK)

$+ \underset{(12.0)}{54.3}$ COSTCA $+ \underset{(1.32)}{5.29}$ D70 $+ \underset{(1.64)}{6.94}$ D74,

$\bar{R}^2 = .975$, DW = 1.26.

<u>Chile</u>

PCUCH $= \underset{(-.243)}{-7.12} + \underset{(43.5)}{1.00}$ PCULME / REXUK $- \underset{(-10.3)}{226}$ (D64

+ 2 . D65 + D66 + D67),

$\bar{R}^2 = .987$, DW = 2.60.

<u>London Metal Exchange: Spot Price</u>

PCULME $= \underset{(-3.14)}{-275} + \underset{(4.12)}{.0871}$ QCWW $- \underset{(-.258)}{.0125}$ $STQQ_{-1}$

$- \underset{(-2.33)}{13.0}$ T $+ \underset{(7.50)}{9.96}$ EUVI . REXUK $+ \underset{(6.04)}{148}$ DEX

$- \underset{(-2.26)}{130}$ D78,

$\bar{R}^2 = .962$, DW = 1.53.

<u>London Metal Exchange: Future Price</u>

PCULMEF $= \underset{(-6.22)}{-92.7} + \underset{(54.7)}{.913}$ PCULME

$+ \underset{(6.47)}{304}$ REXUK $+ \underset{(3.54)}{.0756}$ OAU,

$\bar{R}^2 = .998$, DW = 1.94.

United States: Producer Price

$$PCUUS = \underset{(1.10)}{61.8} + \underset{(3.98)}{.283}\ PCULME / REXUK$$

$$+ \underset{(10.4)}{952}\ COSTUS + \underset{(2.04)}{211}\ D70 + \underset{(1.86)}{212}\ D74,$$

$$\bar{R}^2 = .952, \qquad DW = 1.13.$$

United States: Scrap Price

$$PSUS = \underset{(2.33)}{85.3} + \underset{(20.2)}{.585}\ PCULMEF / REXUK + \underset{(10.4)}{952}\ COSTUS$$

$$+ \underset{(2.04)}{211}\ D70 + \underset{(1.86)}{212}\ D74,$$

$$\bar{R}^2 = .942, \qquad DW = 1.67.$$

East-West Trade

$$QIMWW = \underset{(.175)}{8.76} + \underset{(3.46)}{.556}\ QIMWW_{-1} + \underset{(1.58)}{.320}\ (CMEW - QCREW)$$

$$- \underset{(-2.83)}{2.60}\ PCULME / (REXUK \cdot PCIF) + \underset{(1.94)}{1.57}\ IIPWW,$$

$$\bar{R}^2 = .542, \qquad DW = 2.19.$$

Identities

QCRTW = QCREW + QCRWW

QCRWW = QCRGE + QCRIT + QCRJA + QCROM + QCRUK + QCRUS

QCWW = QCGE + QCIT + QCJA + QCOM + QCUK + QCUS

QIMRUS = - BSUS + QCRUS - QMUS - QSUS + STGUS - $STGUS_{-1}$ + STUS - $STUS_{-1}$ - $STUS_{-1}$ - STWW + $STWW_{-1}$

QMTW = QMEW + QMWW

QMWW = QMCA + QMCH + QMOM + QMPE + QMPH + QMSA + QMUS + QMZI + QMZM

QMWWC = QMCAC + QMCHC + QMOMC + QMPEC + QMPHC + QMSAC + QMUSC + QMZIC + QMZMC

QSWW = QSGE + QSJA + QSUS + QSOM

STWW = STGE + STJA + STLME + STUS + STOM

APPENDIX C: Exogenous Variables Estimates

Year	BSRW	BSUS	COSTCA	COSTCH
1982	0.00	0.00	1.880	26.276
1983	0.00	0.00	1.940	26.700
1984	0.00	0.00	2.050	28.000
1985	0.00	0.00	2.170	29.700
1986	0.00	0.00	2.300	31.400
1987	0.00	0.00	2.450	33.200
1988	0.00	0.00	2.610	35.400
1989	0.00	0.00	2.790	37.600
1990	0.00	0.00	2.990	40.000
1991	0.00	0.00	3.190	42.700
1992	0.00	0.00	3.430	45.500
1993	0.00	0.00	3.670	48.500
1994	0.00	0.00	3.940	51.500
1995	0.00	0.00	4.210	54.500

Year	COSTPE	COSTPH	COSTSA	COSTUS
1982	31.71	2.590	2.500	1.781
1983	32.20	2.630	2.540	1.807
1984	33.80	2.760	2.670	1.899
1985	35.80	2.950	2.820	2.010
1986	37.90	3.090	2.980	2.126
1987	40.10	3.270	3.160	2.249
1988	42.70	3.480	3.360	2.396
1989	45.40	3.700	3.570	2.547
1990	48.30	3.940	3.800	2.710
1991	51.50	4.210	4.050	2.891
1992	54.90	4.480	4.320	3.079
1993	58.50	4.770	4.600	3.282
1994	62.10	5.070	4.880	3.482
1995	65.80	5.370	5.170	3.691

Year	Variables			
	COSTZI	COSTZM	DCH	DEX
1982	30.79	3.340	0	0
1983	31.25	3.390	0	0
1984	32.80	3.560	0	0
1985	34.80	3.770	0	0
1986	36.80	3.990	0	0
1987	38.90	4.220	0	0
1988	41.40	4.490	0	0
1989	44.00	4.780	0	0
1990	46.90	5.090	0	0
1991	50.00	5.430	0	0
1992	53.20	5.780	0	0
1993	56.80	6.160	0	0
1994	60.20	6.540	0	0
1995	63.80	6.930	0	0

Year	Variables			
	DPE	DSPEC	DST	DSTCA
1982	1	0	0	0
1983	1	0	0	0
1984	1	0	0	0
1985	1	0	0	0
1986	1	0	0	0
1987	1	0	0	0
1988	1	0	0	0
1989	1	0	0	0
1990	1	0	0	0
1991	1	0	0	0
1992	1	0	0	0
1993	1	0	0	0
1994	1	0	0	0
1995	1	0	0	0

Year	Variables			
	DSTUS	DZI	EUVI	IIPEW
1982	0	0	160.8	136.6
1983	0	0	173.6	140.7
1984	0	0	187.2	144.9
1985	0	0	202.5	149.3
1986	0	0	219.7	153.7
1987	0	0	238.8	158.4
1988	0	0	260.8	163.1
1989	0	0	283.7	168.0
1990	0	0	309.0	173.0
1991	0	0	336.5	178.2
1992	0	0	365.4	183.6
1993	0	0	395.8	189.1
1994	0	0	428.6	194.8
1995	0	0	462.9	200.6

Year	Variables			
	IIPGE	IIPIT	IIPJA	IIPUK
1982	112.0	124.7	148.4	101.9
1983	111.1	121.3	152.4	104.0
1984	114.1	125.0	157.0	106.8
1985	115.9	129.3	165.0	107.9
1986	118.9	134.5	173.7	109.1
1987	122.7	138.1	184.2	111.6
1988	125.6	142.6	195.0	113.9
1989	129.3	147.4	205.7	116.7
1990	132.8	150.5	219.1	118.6
1991	135.8	154.1	232.5	120.6
1992	137.8	159.4	244.8	122.8
1993	141.0	165.4	256.6	125.5
1994	144.8	171.5	274.8	129.3
1995	150.3	178.6	294.0	132.4

Year	Variables			
	IIPUS	IIPWW	INTEU	INTGE
1982	117.7	118.0	13.11	5.00
1983	123.0	121.0	10.60	4.00
1984	132.1	127.1	9.90	3.80
1985	139.1	132.6	9.80	4.20
1986	144.6	137.6	9.70	5.10
1987	150.7	143.1	9.60	5.00
1988	156.4	148.4	9.40	4.50
1989	161.8	153.8	9.10	4.40
1990	167.6	159.5	8.80	4.20
1991	173.4	165.2	8.80	4.20
1992	179.2	170.6	8.80	4.50
1993	184.7	176.1	8.70	4.60
1994	190.4	182.4	8.60	4.50
1995	196.3	189.2	8.60	4.40

Year	Variables			
	INTUK	PALLME	PALUS	PAU
1982	3.20	812.5	1675.5	375.8
1983	1.80	868.8	1820.0	398.3
1984	.50	1296.0	1973.0	428.6
1985	1.20	1291.0	2140.0	458.2
1986	.20	1365.0	2296.0	485.7
1987	1.40	1471.0	2463.0	514.8
1988	1.00	1618.0	2642.0	545.7
1989	-1.10	1767.0	2834.0	578.4
1990	1.20	1895.0	3040.0	613.1
1991	- .30	2060.0	3246.0	649.9
1992	- .20	2239.0	3466.0	688.9
1993	.20	2440.0	3701.0	730.3
1994	.10	2670.0	3952.0	774.1
1995	- .50	2935.0	4220.0	820.5

Year	Variables			
	PCIF	PWIGE	PWIIT	PWIJA
1982	155.5	138.5	287.9	136.0
1983	164.8	141.4	317.0	135.4
1984	177.3	145.4	344.6	137.2
1985	189.6	151.2	377.7	136.9
1986	201.0	156.8	427.5	137.3
1987	213.0	160.7	484.8	139.5
1988	225.8	164.7	555.6	142.2
1989	239.4	168.5	635.0	147.4
1990	253.8	172.0	722.7	151.3
1991	269.0	176.7	814.4	156.5
1992	285.2	181.6	915.4	160.6
1993	302.3	186.9	1031.6	163.8
1994	320.4	192.1	1153.4	169.6
1995	339.7	197.5	1284.9	174.0

Year	Variables			
	PWIUK	PWIUS	QMCHC	QMPEC
1982	240.3	171.1	1271	399
1983	259.8	173.7	1271	399
1984	282.6	182.5	1315	447
1985	304.4	193.1	1361	457
1986	331.2	204.3	1375	467
1987	357.0	216.1	1381	467
1988	386.3	230.2	1387	467
1989	423.4	244.7	1393	507
1990	457.7	260.4	1399	547
1991	500.7	277.8	14o5	557
1992	545.2	295.9	1411	567
1993	589.9	315.4	1417	577
1994	637.1	334.6	1423	587
1995	689.4	354.7	1429	597

Year	Variables			
	QMZMC	REXCA	REXCH	REXGE
1982	500	1.234	50.9	2.427
1983	500	1.226	50.9	2.440
1984	500	1.214	50.9	2.356
1985	500	1.211	50.9	2.112
1986	500	1.201	50.9	1.985
1987	500	1.202	50.9	1.878
1988	500	1.193	50.9	1.827
1989	500	1.180	50.9	1.746
1990	500	1.167	50.9	1.635
1991	500	1.175	50.9	1.559
1992	500	1.182	50.9	1.484
1993	500	1.186	50.9	1.430
1994	500	1.191	50.9	1.386
1995	500	1.194	50.9	1.354

Year	Variables			
	REXIT	REXJA	REXPE	REXPH
1982	1352.2	249.4	697.57	8.54
1983	1461.9	230.3	698.00	8.54
1984	1540.4	208.8	698.00	8.54
1985	1524.8	193.1	698.00	8.54
1986	1591.9	179.4	698.00	8.54
1987	1701.1	171.1	698.00	8.54
1988	1844.3	162.2	698.00	8.54
1989	1962.0	159.6	698.00	8.54
1990	2009.6	158.8	698.00	8.54
1991	2080.0	155.4	698.00	8.54
1992	2138.8	150.6	698.00	8.54
1993	2212.1	146.0	698.00	8.54
1994	2298.7	143.6	698.00	8.54
1995	2411.1	138.5	698.00	8.54

Year	Variables			
	REXSA	REXUK	REXZI	REXZM
1982	1.083	.5712	5.75	1.08
1983	1.083	.6532	5.75	1.08
1984	1.083	.6570	5.75	1.08
1985	1.083	.6031	5.75	1.08
1986	1.083	.5945	5.75	1.08
1987	1.083	.5974	5.75	1.08
1988	1.083	.6124	5.75	1.08
1989	1.083	.6234	5.75	1.08
1990	1.083	.6234	5.75	1.08
1991	1.083	.6345	5.75	1.08
1992	1.083	.6460	5.75	1.08
1993	1.083	.6592	5.75	1.08
1994	1.083	.6757	5.75	1.08
1995	1.083	.6954	5.75	1.08

Year	Variables			
	STGUS	T	UCCA	UCOM
1982	20.2	29	171.0	379.5
1983	20.2	30	176.5	385.2
1984	20.2	31	186.0	404.8
1985	20.2	32	197.0	428.3
1986	20.2	33	209.0	453.1
1987	20.2	34	222.6	479.4
1988	20.2	35	237.5	510.9
1989	20.2	36	253.7	543.1
1990	20.2	37	271.9	577.9
1991	20.2	38	290.4	616.6
1992	20.2	39	312.2	656.7
1993	20.2	40	334.0	700.0
1994	20.2	41	358.4	742.7
1995	20.2	42	383.2	787.3

Year	Variables			
	UCPH	UCSA	UCUS	UCZM
1982	407.0	377.1	172.4	456.1
1983	413.1	382.8	175.0	462.9
1984	434.2	402.3	183.9	486.5
1985	459.4	425.6	194.6	514.7
1986	486.0	450.3	205.9	544.6
1987	514.2	476.4	217.8	576.1
1988	547.6	507.4	232.0	613.5
1989	582.1	539.4	246.6	652.2
1990	619.4	573.9	262.4	693.9
1991	660.9	612.4	279.9	740.4
1992	703.9	652.2	298.1	788.5
1993	750.4	695.2	317.8	840.5
1994	796.2	737.6	337.2	891.8
1995	844.0	781.9	357.4	945.3