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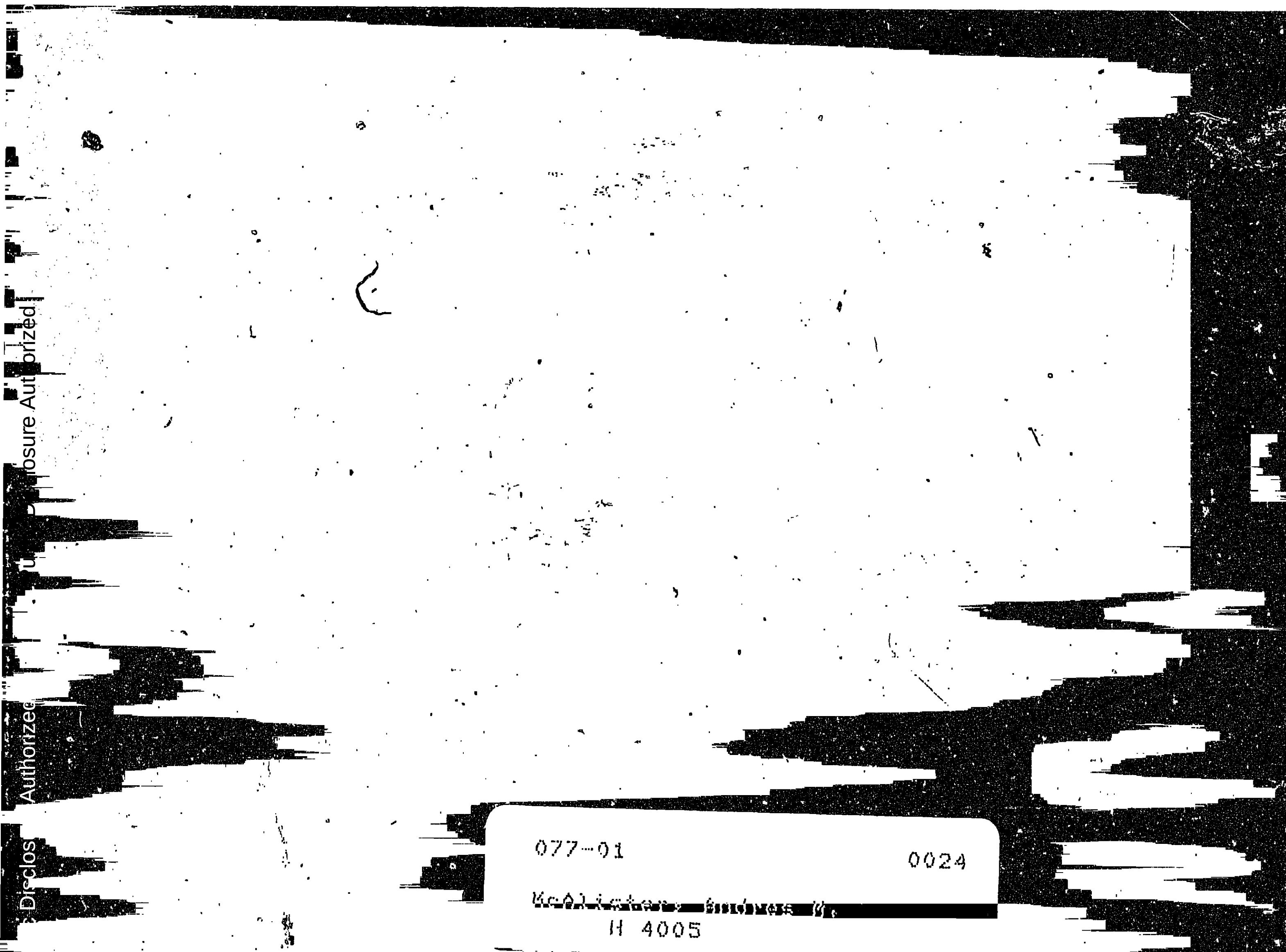
An Econometric Analysis of the World Copper Market

C. Suan Tan



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ABSTRACT

The prolonged economic difficulties since the late 1970s have thrown into sharp relief the structural changes in the world copper market since the mid-1960s and the resulting changes in competitiveness among the major producing countries. This paper analyzes the developments in the world copper market since the mid-1960s. It also describes the specification, estimation and simulation of an econometric model of the world copper market based on this historical understanding of the market.

The econometric model focuses on the copper market in the market economies, with the influence of excess supply from the centrally planned economies accounted for through their net exports to the market economies. Since mine capacity data for producing countries are not available for the pre-1964 period, the model is based on data for the 1964-83 period. To allow for flexibility in analyzing alternative future scenarios, mine capacity expansions are treated exogenously. The results give support to the notion that copper demand and supply are price-inelastic. Copper demand has been influenced primarily by the industrial production of the consuming countries.

Mine capacity expansions up to the 1970s were premised on expectations of continued demand growth. Moreover, the nationalization of the copper industry in some of the developing countries precipitated concern over their future production capabilities and led to some unwarranted investments in capacity expansions in industrial countries. Aside from these unrealized expectations, the decline in the comparative advantage of North American mines, because of declining ore grades, was exacerbated by higher production costs resulting from the imposition of stringent pollution controls and inflationary increases in labor and energy costs. The shift from a unified domestic price for US producers in 1978 to a producers' price equal to the world price plus a premium reflects the reduced North American bargaining strength: the North American share of world production fell from 30% in 1970 to 16% in 1983.

Model simulations give weight to the view that overinvestment and expansion of mine capacity in the 1970s and prolonged world economic recession from the late 1970s to early 1980s precipitated the current oversupply. The situation has been aggravated by the loss of market shares to material substitutes, such as aluminum, owing to a lack of marketing and promotion efforts and to the trend toward miniaturization. This conclusion is substantiated by the results of a simulation with aluminum prices set at one-and-a-half times that of copper. Thus, low and regulated aluminum prices effected a royalties squeeze on the copper industry. Exchange rate variations and inflation were also seen to influence price determination.

While the invention of fiber optics has been frequently cited as a major new threat to the copper industry, the simulation results suggest that fiber optics will displace slightly less than 0.5 million tons out of a total of 9.0 million tons of copper consumption by 1995. Given the crucial role of industrial activity for copper demand and the abundance of copper reserves,

the viability of mine capacity expansions was shown to depend ultimately on copper's ability to withstand competition from other substitutes and to maintain growth in existing and new uses. Thus it may be that growth and development in highly populated and fast-growing countries such as China and India could provide important markets.

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ACKNOWLEDGMENTS

This report is part of a World Bank study of the copper market undertaken jointly by staff from the International Economics Department and Industry Department. The model was developed in the framework of the study of the world copper industry conducted under the leadership of Kenji Takeuchi. Suggestions from Roberto Benjerodt, Shun-Ichi Maeda, John Strongman and Kenji Takeuchi in the course of estimating the model and comments and suggestions from Ron Duncan on successive drafts of this paper are gratefully acknowledged. Hye-Sook Leechor provided assistance in data collection and computation.

I. INTRODUCTION

1.1 Background to the Study

While most primary commodities experienced depressed prices during the prolonged economic recession of the late 1970s and early 1980s, one commodity that also experienced considerable adjustments at the industry level was copper. The copper market provides an interesting study at this juncture because it is a commodity characterized by rapid capacity expansion from the late 1960s through to 1982 by locationally-dispersed producers in both the industrial and the developing countries. Until 1970, copper production was evenly shared between the industrial and the developing countries. Since 1970, however, the distribution of production has been changing in favor of the developing-country group; by 1983 its share had reached 68% of total production in the western world. In contrast, the share of the United States--the largest single copper ore producing country until 1983--has gradually declined from its peak of 30% in 1970 to about 16%. These changes in production shares highlight the developments on the supply side of the copper market in the last 15-20 years and provide a focal point for the study.

The primary purpose of this paper is to describe a model of the world copper market. Development of this model led to questions about market structure and its evolution, answers to which in large part dictate the model structure and the extent of flexibility required to facilitate long-term forecasting. The 1970s, the major part of the sample period for the estimation of the model equations, was a period of major changes in the world economy; it included, importantly, the shift from fixed to floating exchange rate regimes and the shift from low and stable to high and unstable oil prices. These changes complicate the background against which the copper market has to be modelled, making it difficult to assess whether the market has been undergoing irreversible structural changes, or whether the changes observed are only temporary.

1.2 Outline of the Study

The econometric model of the copper market presented here concentrates on the western world market dynamics; i.e., it excludes the market dynamics of the copper industry within the centrally-planned economies (CPEs). The model is one of western world copper supply and demand, with the influence of supply from the CPEs accounted for through their net exports to the market economies.

The model is based on annual data for the 1964-83 period. This choice of sample period was dictated primarily by data considerations, since mine capacity data for individual producing countries are not readily available for the pre-1964 period. Given the interest in studying copper consumption by end-uses and since such data as are available only date back to 1968-70, the analysis of aggregate and sectoral end-use consumption is based on the shorter 1968-1983 period. This short sample period imposes limitations on the usefulness of econometric methods. However, in view of the rapid substitution of copper by aluminum in the 1950s and 1960s, an advantage of using this shorter period for estimation is that it relates to the recent consumption period and is therefore more relevant for the forecasting purposes of this exercise.

The next chapter analyzes refined copper demand and presents estimates of aggregate consumption equations for each of the major consuming countries. The consumption functions are based on input cost-minimization assumptions because of the derived demand for copper. End-use consumption analysis is deferred to Chapter VII.

Chapter III analyzes the supply of primary and secondary copper. To allow for flexibility in analyzing alternative future production scenarios, mine capacity expansions, reflecting investment behavior, are treated exogenously. Chapter IV analyzes the changing composition of US trade in copper, in particular the recent growth in net imports of refined copper. Chapter V analyzes the stockholding and price formation process. Here it is found necessary to differentiate the US domestic producers' price from the price quoted on the London Metal Exchange (LME) which is considered to be the world or market reference price.

The results from empirical validation test of the model are presented in Chapter VI. The model was also simulated to assess (i) the implications of higher aluminum prices than those experienced during the recent historical period and (ii) the impact of different exchange rates than those prevailing in recent years.

Chapter VII analyzes copper consumption behavior when disaggregated into electrical, transportation, construction, general engineering and domestic use industries for the United States, United Kingdom, the Federal Republic of Germany, France, Italy and Japan. For each of these countries, the single aggregate consumption equation is replaced with five end-use consumption equations, after which the model is revalidated. One of the advantages of this end-use consumption approach is that it facilitates explicit treatment of alternative fiber optics adoption rates in the forecasting period.

In Chapter VIII the advantages of fiber optics in the telecommunications industry are discussed. Model simulations are then carried out to project copper demand, supply and price under given GDP growth, inflation and exchange rates in the 1985-1995 period, with and without displacement by fiber optics.

The major findings of the study are summarized in Chapter IX.

II. DEMAND FOR COPPER

2.1 Diversity of Derived Demand for Copper

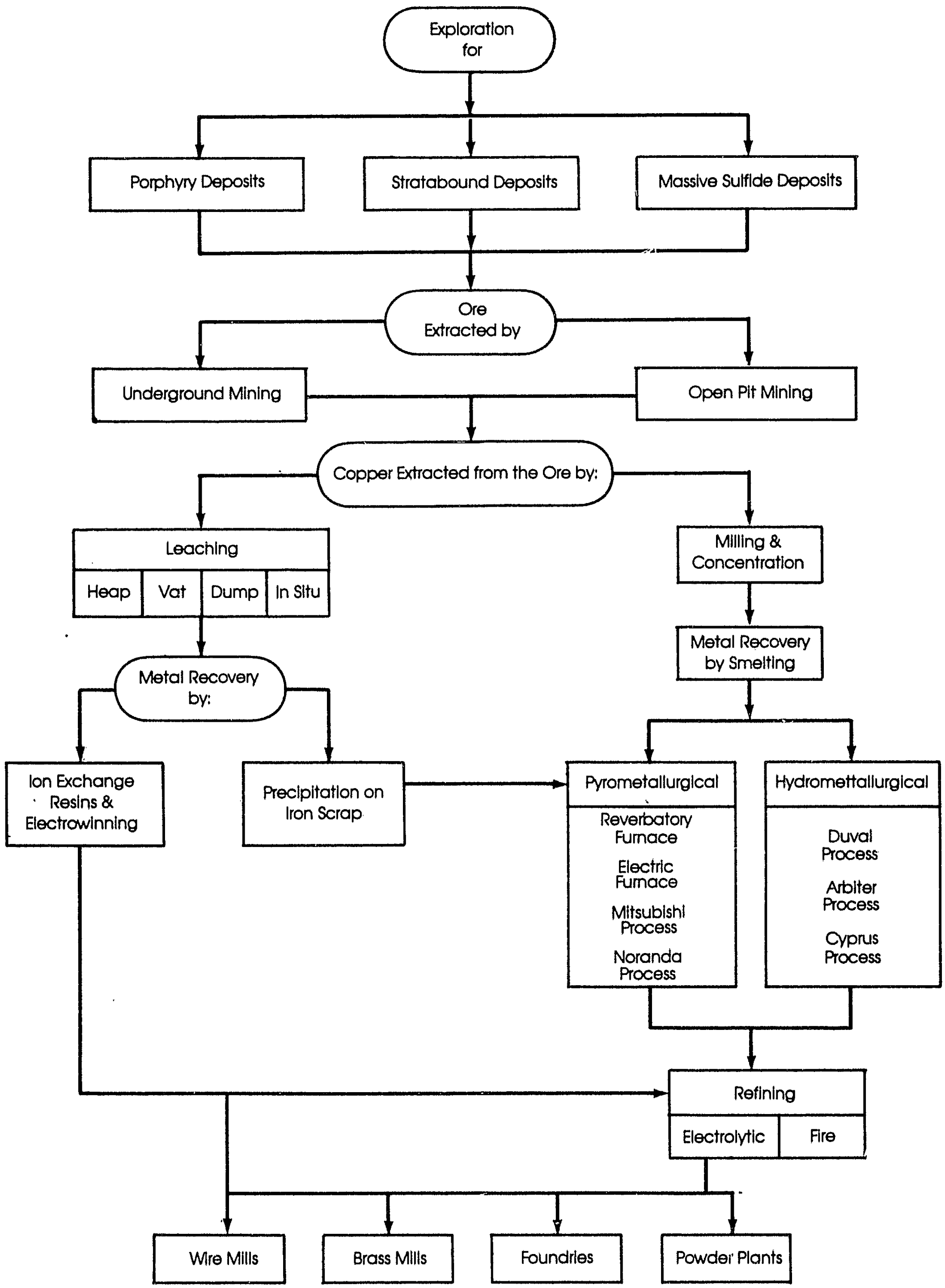
The existence of the copper market stems from the use of copper as an industrial input. The attractive industrial properties of copper are its excellent electrical and thermal conductivity, noncorrodibility, malleability and tensile strength, homogeneity, ability to be alloyed and its aesthetic appeal. Because of these physical properties, copper use has been popular since antiquity.

Today, almost half of all copper production is consumed by the electrical and telecommunications industries which use copper to produce wiring and winding wires, power and telecommunication cables, motors and generators, switchgears, transformers and telecommunication equipment. The other major end uses of copper are in the engineering and capital equipment, construction and transport industries. In the engineering and capital equipment industry, copper is used in the production of valves and fittings, process and welding equipment, engines, electric power stations, pumps, and refrigeration and air-conditioning plants. The construction industry uses copper in producing goods such as water heaters, roofing, fittings and brasswares in plumbing, and in locks. In road transport, copper is used for making radiators, car heaters, cable harnesses and starter motors. In railways, copper is required for locomotive motors and generators and for overhead wiring; while in shipbuilding, copper is used in making propellers, condensers, electrical equipment, valves and sprinklers, and deck fittings.

Figure 2.1 which is adapted from Mikesell (1979:136) is a flowchart of the stages and major forms in which refined copper is consumed within the industrial complex. Basically, refined copper consumption can be distinguished into the intermediate stage of semi-fabricating and the final stage of fabricating. The direct users of refined copper are the semifabricators, consisting of (1) wire mills, (2) brass mills, (3) foundries and (4) powder mills. The fabricators are those end-use industries which consume the copper semi-fabricates to produce final producer and consumer goods. These end-use industries are generally classified under five sectors: (1) the electrical and electronic goods sector, (2) the construction sector, (3) the industrial machinery and equipment sector, (4) the general engineering goods sector and (5) the transport sector.

In modelling the demand for copper, it is possible in principle to model demand at any one of three levels of consumption, that is, (1) total consumption of refined copper, (2) consumption of refined copper by the four semi-fabricators, or (3) direct consumption of refined copper (in the form of semi-fabricates) by the fabricators in the five end-use sectors. In terms of ease of modelling, the total consumption approach is easiest, while disaggregating consumption to the semi-fabricating industries is the most difficult since the corresponding activity variables that determine consumption are not readily available. In this study, the demand for copper has been modelled both at the aggregated and disaggregated (by end-use sectors) levels. In this chapter, the modelling of aggregated consumption will be discussed and the empirical results presented. The modelling of disaggregated consumption is presented in Chapter VII after the global model using aggregate consumption for each country has been empirically validated.

FIGURE 2.1: **TECHNOLOGY OF PRIMARY COPPER PRODUCTION**



The implications of the diversity of the derived demand for copper for the evolution of the market are discussed in the next chapter on copper supply. Suffice to mention here that because of the bulkiness of refined copper in its pre-semifabricated blister form, the major forms in which refined copper are traded are copper wires, electrolytic wirebars, electrolytic copper or cathodes, and bare copper wires. The reference price for copper in the trade has been that for electrolytic wirebars and more recently, for high-grade cathodes. Since the high-grade cathode price is the price for which forecasts are derived from the model, it is the price referred to throughout the paper.

Table 2.1 gives the distribution of refined copper consumption by the main consuming countries/regions for the period 1950-1983, and highlights an important change in the market. During this period, while North American (Canada plus the United States) consumption fell from 49% to 22%, shares were increased by Japan, China, the Republic of Korea, Brazil and the CPEs. This marked decline in the North American share reflects the levelling off of copper-use intensity with technological change and as per capita incomes increase beyond a certain level. North American intensity-of-use (that is, the number of pounds of copper use per million dollars GNP) declined from 1.5 in 1960 to 0.7 in 1983. The intensity-of-use of the newly-industrialized countries such as the Republic of Korea increased from 0.6 to 2.1 during the same period.

2.2 Demand for Copper and Input Substitution

Like many primary commodities, copper is not insulated from competition within its markets. Accelerated substitution against copper began around 1950, the pressure coming mainly from aluminum and plastics. Other less important substitutes include stainless steel, lead, sodium and cadmium. The

TABLE 2.1: SHARES OF TOTAL REFINED COPPER CONSUMPTION OF MAIN CONSUMING COUNTRIES/REGIONS, 1950-1983
(%)

Country/Region	1950	1960	1970	1980	1981	1982	1983
North America	49.1	27.9	28.7	22.2	23.9	20.3	21.6
EC-4	24.6	31.4	25.5	21.1	19.7	20.6	19.9
Brazil	0.5	0.6	1.0	2.6	1.9	2.8	1.6
Japan	2.0	6.4	11.3	12.4	13.2	13.9	13.4
China	-	2.5	2.4	3.5	3.5	4.3	4.2
Rep. of Korea	-	-	0.1	0.9	1.5	1.5	1.7
Comecon	13.4	16.8	17.1	20.8	20.4	21.4	21.4
ROW	25.0	14.6	13.5	16.6	16.0	16.4	15.2
TOTAL	100.0 (2937)	100.0 (4776)	100.0 (7291)	100.0 (9361)	100.0 (9508)	100.0 (8968)	100.0 (9102)

Source: World Bureau of Metal Statistics.

Notes:
1. Figures within parentheses denote total refined copper consumption in thousand metric tons.
2. EC-4 refers to the 4 main industrial countries of the European Community: the United Kingdom, France, Italy, and the Federal Republic of Germany.
3. Comecon refers to the East European countries and the USSR that belong to the Council for Mutual Economic Assistance.

recently-developed fiber optics is the latest substitute making inroads into copper's markets. Brisk (1976) has argued that few materials have been able to compete with copper on a technical basis--that is, in terms of physical properties. Instead, the competition has mainly been on the basis of cost (and hence relative price) and availability (and hence the stability or otherwise of the copper price). Since aluminum has been the dominant substitute, its role will be briefly discussed here.

In physical terms, the competition from aluminum has occurred primarily on the basis of the properties of electrical conductivity and material strength. The electrical conductivity of aluminum is less than that of copper; however, this disadvantage is offset by the lighter weight of aliminum. In electrical terms, a ton of aluminum is approximately equivalent to two tons of copper.

In view of its lightness, aluminum has replaced copper mainly in applications where its lower weight provides an advantage and where space is not a constraint, such as in high-voltage overhead transmission cables, packaging and electrical engineering, housing construction, in some sectors of the transport industry where the light weight of aluminum is a critical advantage in an energy-conscious setting, and in armature construction of small motors and generators.

The present-day competition between copper and aluminum can be traced to differences in the evolution of the two industries over the last century and the differential growth in knowledge about their industrial applicabilities. While uses for copper have been known since antiquity, the modern demand for copper was stimulated by the discovery of electricity and the growth of the electricity-related and telecommunications industries. In contrast, industrial uses of aluminum were only developed when the electrolytic process of separating out the metal became available in the 1880s. Thus, at a time when the copper industry was preoccupied with expanding production to meet demand, the aluminum industry's concern was R & D to reduce production costs and to develop new uses. From Table 2.2 it can be seen that R & D efforts by the aluminum industry began to pay off by 1950 when total world (including the CPEs) consumption reached one-half the world copper consumption. By 1970 aluminum consumption had surpassed copper consumption by nearly one-half. Other reasons for the present situation in the copper market relate to the reduction in concentration in production activities and the nationalization of copper mines in the major developing producing countries. These events led to increased competition in the industry with attention focussed on increasing productivity to reduce production costs but with little attention to market development. 1/ For further details on the industrial and market development of these two metals, see Mardones et al. (1985).

Up to the end of the 1970s, aluminum also had the advantage of lower and more stable prices than copper. The lower price has been attributed to technical progress in developing a new material while the price stability has been due largely to market structure. For example, the US price of aluminum is administered by the producers and varies only infrequently. In Europe, the

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1/ The copper industry has traditionally spent much less on R & D and marketing than the aluminum industry. For example, according to the International Copper Research Association (INCRA), the 1985 R & D expenditures of the 19 copper development groups sponsored by the copper industry was less than half of the increase of $22 million expended by Alcoa alone. In 1985, Alcoa's R & D budget exceeded $100 million.

TABLE 2.2: TOTAL WORLD CONSUMPTION OF COPPER AND ALUMINUM, 1890-1983

('000 TONS)

Year	Copper	Aluminum
1890	288.5	0.2
1900	512.7	7.3
1910	921.8	44.2
1920	929.0	131.9
1930	1639.4	205.9
1940	2711.1	822.8
1950	3009.3	1583.6
1960	4755.8	4177.3
1970	7291.3	10027.9
1980	9361.3	15285.4
1982	9067.2	14145.3
1983	9113.2	15388.4

Source: Mardones, Silva and Martinez (1985).

price of aluminum on the LME was also moderately controlled during parts of the 1948-68 period (Fisher et al., 1972). The price differential between copper and aluminum widened between 1964 and 1974 when conflicts between the copper firms and the governments of the developing producing countries restricted the growth of copper supply and kept copper prices above production costs. In the early 1970s, copper prices rose sharply like all other commodity prices due to monetary expansion, but the increase in copper prices was exacerbated by severe supply shortages--due partly to the political change in Chile. More recently, prices have fallen sharply and production cutbacks have been undertaken. It can be seen that the relative copper-to-aluminum price ratio was about 1.4 in the 1950s; during the period 1964-74 it ranged between 1.6 and 2.8. Since the mid-1970s, the ratio has tended towards unity or less.

2.3 Specification of Copper Input-Demand Functions

In general, copper's share of the total input cost of final goods is small, so that the demand for copper in the short- to medium-term is not dictated by the copper price *per se*. Rather, the level of derived demand results from overall cost-minimization in the production of the final good.

Suppose the production of a quantum of final good Q is given by:

$$Q = Q\ \{\ K,\ L,\ I^{cu},\ \underset{\sim}{I}^{o},\ T\ \}$$

where K is the capital input

L is the labor input

I^{cu} is the copper input

$\underset{\sim}{I}^{o}$ is the vector of all other inputs

and T is the technology employed in the production of Q.

Assuming cost-minimization in the production of Q, the copper input demand function is then given by:

$$C = C\ \{Q,\ P^{cu},\ \underset{\sim}{P}^{o},\ T\}$$

where Q and T are defined as before, P^{cu} is the price of copper and $\underset{\sim}{P}^{o}$ is the vector of all other input prices.

The demand function may be simplified by replacing the vector of other prices with the aluminum price. If the substitution between copper and aluminum is homogeneous for the final goods Q, the input demand function may be written as:

$$C = C\ \{Q,\ (P^{cu}/P^{al})\ ,\ T\}$$

where (P^{cu}/P^{al}) is the relative price of copper to aluminum. However, the use of this relative price may be too rigid. If Q is non-homogeneous, the substitution between copper and aluminum in Q-production is also likely to be non-homogeneous. To allow for non-homogeneity, the input demand function may be specified in terms of the real prices of copper and of aluminum:

$$C = C \{Q, \quad P^{cu}/PI, \quad P^{al}/PI, \quad T\}$$

where PI is the price index used to deflate the input prices.

The above specification implies substitution with respect to current prices only. It is well known in industry that the extent of short-run input substitution arising from relative price changes is constrained by the technology in use and the machinery and equipment in place. This means that input substitution beyond certain limits may incur adjustment costs, so that potential savings from input substitution have to be weighed against the potential adjustments costs. In general, input substitution occurs only after the relative price change is perceived as likely to persist, thereby making the demand for copper a function of lagged real copper and aluminum prices.

Since primary copper producers are generally located at a distance from the copper semi-fabricators and fabricators, the fabricators and semi-fabricators are known to hold stocks of refined copper and copper semi-fabricates to ensure uninterrupted input supply. Thus, the refined copper consumption reported in each period need not go towards semi-fabricates and final goods production in the same period. Conversely, the production of final goods in any period may be partly from the stock of copper intermediates derived from refined copper consumption in the past period. Ceteris paribus, refined copper consumption in each period may not be satisfactorily explained by the level of final goods production alone. One way of modelling such consumer behavior is to assume only partial adjustment in any period to the derived level of consumption. This specification gives rise to the introduction of a lagged refined copper consumption variable (C_{-1}) which reflects the stockholding by the semi-fabricators and fabricators.

A trend variable (T) is included in the input-demand function to proxy technological change that might have caused the shift away from copper. The general form of the input-demand function to be estimated becomes:

$$C = C\ \{IPI,\ (P^{cu}/PI)_{t-i},\ \ (P^{al}/PI)_{t-i},\ \ C_{t-i},\ T \mid i = 0,\ 1,\ 2,\ ....\}$$

where Q is proxied by the industrial production index (IPI).

Before estimating the consumption equation it is necessary to consider the question of the appropriate functional form. The linear form, while simple, imposes the assumption of an additive relationship. This means that consumption is determined separately by the level of industrial activity, the price of copper and the price of aluminum, and by the rate of technological change, but without any interaction among the activity, price and technology variables. The additive relationship also imposes the assumption that irrespective of the initial price level, any change in price will result in a fixed change in consumption given by the price coefficient. Given the volatility in copper prices, assumptions of an additive relationship are probably too stringent. In contrast, the multiplicative form allows for interaction among the explanatory variables. Preference is also given to the multiplicative form, since the loglinear regression estimates can be interpreted directly as elasticities and price-induced changes in consumption are derived in terms of proportions.

2.4 Estimation of the Consumption Functions

Although consumption data are available from the 1950s, it was decided to concentrate on the period from the mid-1960s for two reasons. First, the impact of substitution has been significant since the 1960s. As the pattern of substitution varies between different end-uses, it is necessary to analyse consumption by end-uses. Second, data on copper end-uses are not available before the late 1960s. The use of this shorter time-period has the advantage that it is the period after structural changes on the supply side of the copper market had occurred. This supply side structural change will be discussed in the next chapter.

Refined copper end-use analysis is important for evaluating the future demand for copper, because of the differential impact of the various substitutes. However, data on end-uses are not readily available, except for a few industrial countries and after 1968. Since the aim is to use the total and end-use, or sectoral consumption estimates jointly, 1968 is taken as the starting year for the analysis of both total and sectoral consumption. However, all the total consumption equations were estimated for the 1956-1983 period also so as to compare the elasticities of demand with respect to activity and prices in the two periods. In each case the additive forms of the equations were also estimated to provide a comparison of the constant elasticities derived from the multiplicative form with the average elasticities derived from the linear form.

The consumption data were obtained from World Metal Statistics published by the World Bureau of Metal Statistics. Industrial production indices were obtained from national sources while the prices of copper and aluminum were extracted from Metal Statistics published by Metalgesellschaft. The equations for refined copper consumption in individual countries are discussed below in alphabetical order. Ordinary Least Squares (OLS) regression estimation was used throughout.

For all equations the prices of copper and aluminum were introduced either separately or as relative prices. Where they are used separately, the prices were first converted into the local currency of the consuming country concerned and deflated by its consumer price index. Except for the United States and Canada, the LME copper price was used throughout. For the United States and Canada, the US producers' price was used. Similarly, the LME aluminum price was used for countries outside North America, but the US aluminum producers' price was used for the US and Canadian equations. For the four West European industrial countries, the aluminum price quoted in the German market was used alternatively with the LME price; the final choice of the price to use here was made on the basis of the estimates obtained. For all countries, the index of industrial production served as the activity variable. Table 2.3 presents the empirical results for the copper consumption equations. Figures within parentheses are the t-values of the corresponding OLS estimates. RHO(i) refers to the first (i=1) or second (i=2) order autocorrelation coefficients using the Cochrane-Orcutt iterative method.

As explained earlier, the 1968-1983 period was chosen as the estimation period for the model in order to harmonise with the end-use analysis for this period, and to reflect the market structure since the late

TABLE 2.3: ESTIMATION RESULTS FOR REFINED COPPER CONSUMPTION EQUATIONS, 1968-1983

Country/ Region	Constant	IPI	TIME	p^C	p^A	p^C/p^A	CR_{-1}	$\bar{R}^2$	RHO	DW	F
Brazil		1.40 (9.9)	-0.02 (-1.2)	-0.14 (-2.6)				0.95		2.28	$F_{3,13}$ = 87.25
Canada	2.10 (1.7)	1.15 (5.0)	-0.05 (-5.7)	-0.56 (-3.6)	0.37 (2.7)			0.69	ρ (1) = -0.46	2.08	$F_{4,10}$ = 8.79
China	2.52 (3.3)	0.27 (2.4)		-0.15 (-1.6)			0.54 (3.8)	0.96		1.70	$F_{3,12}$ = 128.52
France	2.30 (1.6)	0.36 (1.8)		-0.09 (-1.1)	0.55 (1.7)			0.73	ρ (1) = 0.97 ρ (2) = -0.56	1.88	$F_{3,10}$ = 12.64
Germany, Fed. Rep. of	5.18 (9.6)	0.39 (3.2)	-0.02 (-2.4)			-0.24 (-3.6)		0.82		2.01	$F_{3,12}$ = 23.53
India (linear)	1.79 (1.8)	0.56 (2.7)				-0.04 (-0.2)	DV7477 -0.56 (-3.2)	0.70		1.97	$F_{3,12}$ = 12.43
Italy	2.12 (6.6)	0.83 (9.4)	-0.01 (-1.7)			-0.13 (-3.1)		0.98	ρ (1) = 0.17 ρ (2) = 0.52	2.10	$F_{3,10}$ = 184.92
Japan	5.51 (14.4)	0.33 (4.2)				-0.34 (-5.5)		0.92		2.07	$F_{2,13}$ = 84.38
Korea, Rep. of		0.52 (13.1)		-0.01 (-2.1)				0.95	ρ (1) = 0.40	1.84	$F_{2,11}$ = 103.95
United Kingdom		1.55 (53.0)	-0.03 (-8.3)			-0.21 (-3.6)		0.95		2.26	$F_{3,13}$ = 91.66
United States	1.47 (1.7)	1.65 (7.4)	-0.06 (-7.0)			-0.32 (-3.7)		0.78		2.23	$F_{3,12}$ = 19.05
ROWW	537.04 (3.4)		28.22 (5.9)	-4.78 (-2.7)				0.96	ρ (1) = 0.75 ρ (2) = 0.30	1.82	$F_{2,13}$ = 159.54

Notes: p^C refers to the deflated price of copper;
p^A refers to the deflated price of aluminum;
p^C/p^A refers to the relative price of copper to aluminum.
ROWW refers to Rest of Western World (market economies).
Results are from loglinear equations except where stated.
Figures within parentheses refer to t-statistics of their corresponding regression estimates.

1960s. Given that this is a relatively short period, all equations were also estimated for the 1956-1983 period. Comparison of these equations facilitated an assessment of the structural change hypothesized, and of the stability of the estimated elasticities. Although the estimation results for the 1956-83 period are not presented, their implications are discussed.

In general, the elasticity estimates for refined copper consumption did not change no matter whether a linear or loglinear specification was used. Since the loglinear estimates can be interpreted directly as elasticities, this form was preferred. Where the linear specification gave significantly superior estimates (in terms of statistical significance), the linear form was used.

From the results of Table 2.4 it can be seen that the demand for refined copper is determined primarily by the level of industrial production. However, there is a large variation in the estimated elasticities of copper consumption with respect to the index of industrial production. The countries in the sample can be differentiated into those with elasticities greater than or less than unity. Countries with elastic copper consumption with respect to industrial activity are Brazil, Canada, the Republic of Korea, the United Kingdom and the United States. For the remaining major consuming countries, the elasticity for Italy was close to unity while for China, France, the Federal Republic of Germany, India and Japan the estimated elasticities were less than unity. While Japan is known to be an important copper-consuming country, its consumption elasticity with respect to industrial activity in the 1968-1983 period has been only about 0.4 as compared to 1.7 for the United

TABLE 2.4: COPPER DEMAND ELASTICITIES WITH RESPECT TO THE INDUSTRIAL PRODUCTION INDEX AND PRICES (1968-1983)

Country	Industrial Production Index	Own Price	Cross Price (Aluminum)	Relative Price
Brazil	1.5	-0.10		
Canada	1.2	(-0.56)	(0.37)	
China	0.1			
Germany, Fed. Rep. of	0.4			(-0.13)
France	0.4	(-0.34)	(0.64)	
India	0.6			(-0.10)
Italy	0.8			-0.12 (-0.26)
Japan	0.4			(-0.25)
Rep. of Korea	1.2	-0.22		
United Kingdom	1.5			-0.21
United States	1.7			-0.21

Note: Figures within parentheses refer to long-run elasticities.

States. Various arguments can be advanced to explain these varying elasticities. For example, despite reasonably large copper reserves, India has had to depend on copper imports because of difficulties with its domestic production and processing. In the face of a foreign exchange shortage in 1973, Indian copper consumption was regulated through high import and excise duties so as to encourage substitution by aluminum, in which India is selfsufficient. In estimating the Indian consumption equation, a dummy variable for the 1973-1977 period was used to reflect the period when consumption dropped by nearly 50% because of the import restrictions and because copper use in electrical conductors, household wiring and the manufacture of kitchen utensils was prohibited (Copper Studies, 1978/1). For the remaining countries, the cross-country differences in copper consumption elasticities with respect to their industrial production led to a comparison of these elasticities with their materials intensity of GNP measures. It is found that countries (such as the Federal Republic of Germany and Japan) with high intensity-of-use of copper with respect to GNP (IOU) have low elasticity of consumption with respect to industrial production index (γ^{IPI}). The converse holds for countries such as Brazil and the United States. While in-depth examination of these behavioral differences lies beyond the scope of this study, an intuitive explanation can be offered based on inter-country differences in the relative shares of copper-using industrial product in total industrial product. That is, countries with high γ^{IPI} /low IOU would have relatively smaller shares of copper-using industrial production out of their total industrial production than countries with low γ^{IPI} /high IOU.

The estimates in Table 2.4 indicate that copper consumption is responsive to the influence of copper and aluminum prices. For Brazil, Canada, China, France and the Republic of Korea, the best results were obtained when copper and aluminum prices were introduced separately, with consumption in Brazil being affected by copper prices alone. For the remaining countries, the relative price variable gave the best results. Overall, consumption was found to be unresponsive to price movements in the short run (within one year); and even for the long run, the own- and cross-price elasticities are less than unity. Similar elasticities were obtained when the equations were estimated for the 1956-83 period.

Given that there has been substitution away from copper for technological reasons, a trend variable was used to capture that part of the technologically-induced consumption shifts. The trend variable was found to be significant for Canada, the Federal Republic of Germany, Italy, the United Kingdom and the United States and, as Table 2.5 shows, in terms of this estimate the shift away from copper was found to vary between 1% and 6% annually during the 1968-1983 period.

Only in China was the lagged consumption variable significant. This result may be due to it being a planned economy with the lagged consumption variable reflecting a certain inventory policy behavior.

TABLE 2.5: TREND OF DISPLACEMENT OF CONSUMPTION

(percent per annum)

Country	Rate of Growth
Brazil	-2.3
Canada	-4.9
Federal Republic of Germany	-0.6
Italy	-0.8
United Kingdom	-3.4
United States	-6.2

III. PRIMARY AND SECONDARY COPPER SUPPLY

3.1 Changing Shares of Major Producing Countries

Copper occurs in three classes of deposits: namely (1) porphyry-type deposits; (2) strata-bound deposits; and (3) massive sulphide deposits. Of these categories, porphyry deposits are the most widespread and constitute the largest share of copper reserves in the market economies.

According to Mikesell (1979:47), the porphyry deposits that are presently economical to mine are in Chile, Peru, Northern Mexico, Southwestern United States, Western Canada, Papua New Guinea and the Philippines. These porphyry deposits account for a large share of present-day world copper supply. The other major producing areas are in Zaire and Zambia where the deposits are of the strata-bound type.

Although most of the copper produced in the Comecon countries is consumed within these economies, Comecon plays a role in the copper market because of its net exporting position. Table 3.1 summarises the distribution of mine production during the 1950-1983 period, and shows the changes in market shares accompanying the 6.8% annual average rate of growth in production during the 1950-1983 period. Most significant of the changes in output share is the decline of North America (the dominant producer until the 1970s) from about 42% in 1950 to 20% in 1983. In contrast, the share of the Comecon countries rose from 10% to 21% over this period. Although Chile has become the single largest producer since 1983, the South American share only grew from about 15% in 1950 to 19% in 1983. The other growth areas have been Australia, Papua New Guinea and the Philippines which jointly grew from 1% to 9%. The share of the African-producing countries (Republic of South Africa, Zaire and Zambia) declined from about 20% to 15% over the same period.

TABLE 3.1: SHARE OF COPPER ORE MINE PRODUCTION OF MAIN PRODUCING COUNTRIES AND REGIONS, 1950-1983
(%)

Country/Region	1950	1960	1970	1980	1981	1982	1983
North America	42.2	32.5	34.2	24.1	26.8	21.4	20.3
South America	15.6	16.8	14.1	18.4	17.0	19.5	19.3
Zaire & Zambia	18.8	20.7	16.9	13.6	13.2	12.6	12.4
South Africa	1.3	1.2	2.3	2.7	2.6	2.5	2.6
The Philippines	0.4	1.0	2.5	3.9	3.6	3.6	3.3
PNG	-	-	1.7	1.9	2.0	2.1	2.2
Australia	0.6	2.6	2.5	3.1	2.8	3.0	3.2
Comecon	10.1	13.3	17.1	20.8	18.8	20.3	21.1
ROW	23.6	10.4	8.5	12.5	13.3	15.0	15.6
TOTAL	100.0 (2524)	100.0 (4238)	100.0 (6403)	100.0 (7864)	100.0 (8306)	100.0 (8187)	100.0 (8192)

Source: *World Metal Statistics*.

Notes: Comecon refers to the countries belonging to the Council for Mutual Economic Assistance.
Figures within parentheses refer to production in thousand tons.

3.2 Specification of the Primary Supply or Mine Production Function

By primary supply is meant the mine production of copper ore. Given the time lags involved in new mine development and expansion of existing mines, mine production in each time period is constrained by existing mine capacity. In specifying a function for mine production, the existing mine capacity will be taken as given. Thus the hypothesis of constrained profit-maximization or profit-maximization subject to given capacity will be used.

Suppose the mine production Q is defined by the Cobb-Douglas production function $Q = AK^{\alpha}L^{\beta}$, where K and L are the variable capital and labor inputs used to work the existing mine capacity C^*. The constrained profit-maximization problem of maximising profits subject to capacity $C \leq C^*$ can be expressed by maximising the Lagrangean V:

$$\begin{aligned} V &= \text{Profits} + \lambda\,(C-C^*) \\ &= (TR-TC) + \lambda\,(C-C^*) \end{aligned}$$

where TR is the total revenue, which is the product of output price P and output volume Q;

TC is the total variable cost of producing Q, given C*

C is the mine capacity utilized and

C* is the existing mine capacity.

Rewriting the Lagrangean, we get

$$\begin{aligned} V &= TR - TC + \lambda(C-C^*) \\ &= P.Q - (p_L L + p_K K) + \lambda(C-C^*) \\ &= P(AK^{\alpha}L^{\beta}) - p_L L - p_K K + \lambda(C-C^*) \end{aligned}$$

From the first-order conditions, the constrained profit-maximization is attained when the capital and labor inputs used are such that the capital-labor ratio is inversely proportional to the factor prices. The mine production function can then be specified as a function of the copper output price (P), the variable input costs ($p_L L + p_K K$) and mine capacity C*:

$$Q \quad = f\{P,\ p_L L,\ p_K K,\ C^*\}$$

During estimation, a modified version of the basic specification was used for various reasons. These concern the presence of co-products and/or by-products, the problem of obtaining data on the variable input costs, and the dynamic nature of supply behavior.

In general, copper mining involve co-products and/or by-products. This means that copper production will also be affected by the prices of by- and co-products. Hence the prices of the co-products and/or by-products should be included, where relevant, as explanatory variables to reflect the importance of the co-product and/or by-product credits in sustaining the mine production of copper.

In the above specification, variable input costs are shown to be important for constrained profit-maximization. Since input costs data are not readily available, the simplified approach is to deflate the output price by a price index that would approximately reflect the rate of increase in the variable costs. In the estimation process, the consumer price index has been used first to deflate the output prices. Where this deflation failed to yield acceptable results, the wholesale price index or the international export unit value index for manufactured goods (the World Bank's Manufactures Unit Value Index, the MUV) were used as alternative deflators.

So far, specification of the mine production function has been couched in static terms. But it is known that production is affected not only by the current price of copper (P), copper co-products (P^{co}) and copper by-products (P^{by}) but also by the ratio of producers' stockholdings to output (PSTK/Q). Where data on producers' stockholdings are not available, and based on the partial adjustment theory, lagged prices are also introduced. The mine production function estimated took the following general form:

$$Q = f\{C^*, (P/CPI)_{-i}, (P^{co}/CPI)_{-i}, (P^{by}/CPI)_{-i}, (PSTK/Q)\} \text{ for } i=0, -1, \ldots$$

3.3 Data Used in the Mine Production Equations

Unlike the data used in estimating demand, the data used in estimating supply necessitated use of unpublished data that warrants detailed description. The mine production and producer stocks data used were taken from World Metal Statistics (published by the World Bureau of Metal Statistics). Data on individual country statistics, namely the exchange rate, wholesale and consumer price indices, were obtained from the IMF's International Financial Statistics. The data on mine capacity were obtained from an unpublished private source and a description of the method by which these capacity data have been compiled is given below.

Annual mine capacity data for the period since 1964 were obtained from one of the major US producers. Besides data for total non-socialist world mine capacity, data are also available for Australia, Canada, Chile, Papua New Guinea, Peru, the Philippines, South Africa, the United States, Zaire and Zambia.

The mine capacity data refer to capacity at the start of the year. For each country, the mine capacity data are compiled by aggregating the effective (or normal) capacity of all mines in the country. "Effective Capacity" is defined as the capacity of an open-pit mine operating on 3 shifts per day for about 315 days per year. The grade of ore for each mine is the average grade of ore body as given by the individual mine operator.

The operating schedule of a typical open-pit mine owned by the producer who supplied the data was used as the reference mine. For a good marketing year, the typical year-round operating schedule of a mine is 26 consecutive days operation, followed by 2 off-days (that is, when the mine is idle) and a 3-week shutdown during the summer. The total number of operating days per year approximates 315. For open-pit mine capacity figures provided by the individual mine operators, the data were checked first to see if the basis for their derivation was similar to the assumptions used by the producer collecting the data. If the basis differed, the figures obtained from the mine operators were adjusted for consistency.

Since the operating schedule for underground mines is different from that of open-pit mines, the norm of 315 operating days per year cannot be applied. In an underground mine, a typical operating schedule consists of one day for blasting and drilling, 5 to 6 days for continuous mining and one day for resting. Because of the numerous aspects of underground mining which render generalizations and standardizations inappropriate, the underground mine capacity figures provided by the mine operators were accepted without adjusting them to conform to the assumptions for open-pit mining.

The effective or actual capacity of the non-socialist world was taken to be 92% of the total nominal capacity. The 92% figure was obtained from an examination of the historical data which shows that non-socialist world mine production has been about 92% of the nominal capacity. While the 92% adjustment factor may be valid for obtaining effective total world capacity for the non-socialist world, it cannot be applied to the capacity data for individual countries, some of which have exhibited higher than full-capacity utilization rates in many years. In this study of annual production, the individual country's effective capacity in each year was obtained as the sum of the effective capacity at the start of the year and one-half the incremental effective capacity during the year.

3.4 Estimation Results for Mine Production Equations

Separate equations were estimated for the mine production of Australia, Canada, Chile, Mexico, Peru, the Philippines, Papua New Guinea, South Africa, the United States, Zaire, and Zambia. For the balance of western world mine production, a ROWW equation was estimated. The mine production function specified earlier was made country-specific through the use of the relevant co-product and/or by-product prices and the exchange rate to convert the LME price into local currency before deflation by the consumer price index. For the United States and Canada, the US producers' price was used instead of the LME price.

The capacity expansion in any year is taken to be the net result of new investment coming onstream and the closure of mines that are unprofitable on the basis of prices in the recent period. Thus mine production in any year is determined by price, subject to the capacity constraint. The additive specification was preferred in estimating the mine production (supply) equations for all countries except Zambia and the ROWW. In the latter group of countries, the loglinear (multiplicative) specification yielded statistically-better estimates.

Table 3.2 presents the supply equation estimates for individual country mine production during the 1964-83 period. Mine production is predominantly explained by mine capacity. Although by-product and co-product prices were introduced in those countries where they are relevant, they failed to yield significant estimates, except for Zaire. Chilean mine output was explained by mine capacity only; the higher-than-unity value for the Chilean mine capacity variable reflects the fact that Chilean production was consistently higher than estimated capacity throughout much of the period.

Some modifications were introduced in estimating supply equations for the United States and Zaire. Recently, the US industry has been claiming that subsidized supply elsewhere in the copper industry was affecting its profitability. An examination of US copper trade revealed a recent marked increase in copper imports. The specification for the US mine production function was therefore modified by inclusion of the net copper imports variable to reflect the impact of copper imports on domestic production. Dummy variables for the years of labor strikes in the US copper industry were also incorporated; however, only the dummy variable for the severe strike years of 1967-1968 were significant. The coefficient on the net imports variable was significant and had the expected negative sign. Therefore, the decrease in mine production in the United States most likely can be explained by the fall in the copper price and the increase in copper imports.

In the equation for Zaire, a dummy variable for the 1978-80 period was introduced to capture the production loss during that time because of the

TABLE 3.2: ESTIMATION RESULTS FOR MINE PRODUCTION EQUATIONS, 1964-1983

Country/Region	Constant	MCAP	PUS	PLME	$PLME_{-1}$	Σ_i $PLME_i$	Time	DV	$\bar{R}^2$	RHO	DW	F
Australia	-	0.93 (46.9)		0.46 (2.3)					0.95	ρ (1) = 0.13 ρ (2) = 0.57	1.79	$F_{2,12}$ = 127.24
Canada	10.03 (0.1)	0.64 (5.9)	6.20 (1.8)						0.86	ρ (1) = 0.49	1.73	$F_{2,16}$ = 54.35
Chile	-163.48 (-7.0)	1.16 (44.4)							0.98	ρ (1) = 0.40	1.95	$F_{1,17}$ = 1104.99
Mexico	0.51 (1.5)	0.75 (16.5)		0.09 (1.7)					0.94		1.24	$F_{2,17}$ = 149.24
Peru	-71.73 (-1.5)	0.97 (10.1)		0.01 (2.0)					0.92	ρ (1) = 0.26	1.72	$F_{2,16}$ = 97.93
The Philippines	-	0.74 (21.8)				0.21 (4.3)			0.90	ρ (1) = 0.20	1.77	$F_{2,11}$ = 57.21
Papua New Guinea	90.74 (3.6)	0.68 (5.6)					-1.33 (-1.4		0.73		1.71	$F_{2,9}$ = 16.13
South Africa	-	0.93 (42.5)		0.57 (3.4)					0.96		1.78	$F_{2,18}$ = 258.27
USA	453.84 (2.0)	0.44 (3.1)	15.65 (2.2)				NMUSA -0.56 (-2.1)	-254.27 (-3.2)	0.70	ρ (1) = 0.41	2.25	$F_{4,14}$ = 11.38
Zaire	-	0.86 (18.5)			0.23 (1.7)			-41.74 (-2.0)	0.90	ρ (1) = 0.67	1.74	$F_{3,16}$ = 54.51
Zambia	0.84 (1.1)	0.83 (7.0)		0.08 (2.8)					0.82		2.25	$F_{2,17}$ = 43.56
ROWW	-1.29 (-1.1)	1.20 (8.3)		0.04 (0.5)					0.92		1.77	$F_{2,17}$ = 114.77

Notes: MCAP refers to mine capacity;
PUS refers to US domestic producers' price of copper;
PLME refers to LME price of copper;
DV refers to dummy variable;
NMUSA refers to US net imports of copper.

political troubles in the Shaba province. There was a marked increase in the cobalt price in the sample period and the coefficient on the price of cobalt was significant. However, in consideration of the intended use of the model for forecasting and since cobalt prices are unlikely to regain such heights, the cobalt price was omitted as an explanatory variable for Zaire's mine production so as to avoid unrealistically high forecasts of Zairean production.

For Zambia, mine output during the 1965-1983 period was explained by the mine capacity and the LME copper price (deflated by the Zambian consumer price index after conversion into kwachas). In 1970, Zambian production fell because of the accident at the Mufulira mine, and in 1971, 51% of the copper industry was nationalized. As Zambian production was affected by these events, dummy variables were introduced to proxy the production shortfall in these two years. Separate dummy variables for 1970 and 1971 and a dummy variable for 1970-71 were alternatively used in separate estimations of the mine production equation. Although the coefficients estimated for these dummy variables were significant, their inclusion did not enhance the explanatory power of the equation. For this reason, the dummy variables were not used in the final equations.

From Table 3.3, which presents the estimated elasticities of mine production with respect to mine capacity and price for the period 1964-1983, it can be seen that mine production is rather elastic with respect to capacity but very inelastic with respect to price. Price elasticities of less than 0.2 have been derived for the Philippines, Zaire, Zambia, South Africa and rest-of-the-world, while elasticities of 0.2 to 0.3 were obtained for Australia, Canada and the United States. In the case of Chile and Papua New Guinea the

TABLE 3.3: PRIMARY SUPPLY ELASTICITIES WITH RESPECT TO MINE CAPACITY AND PRICE, 1964-1983

Country/Region	Supply Elasticities with Respect to	
	Mine Capacity	Copper Price*
Australia	0.95	0.05
Canada	0.76	0.32
Chile	1.20	-
Papua New Guinea	0.68	-
Peru	1.10	0.23
The Philippines	0.83	0.17
Mexico	0.81	0.23
South Africa	0.93	0.08
USA	0.54	0.25
Zaire	0.94	0.07
Zambia	0.93	0.07
Rest-of-Western-World	1.05	0.10

Note: Except for the Philippines and Zaire where lagged prices are used in the equation, all prices refer to current prices.

price variable was insignificant. This result may be due to the price effect being captured through the mine capacity variable as seen from the sharp year-to-year variations in the mine capacity variable--especially for Chile. These price elasticities are similar in magnitude to those estimated by Koss (1985) of 0.17, but are lower than Wagenhals' (1983) estimates which range from 0.06 to 0.51 for a similar period.

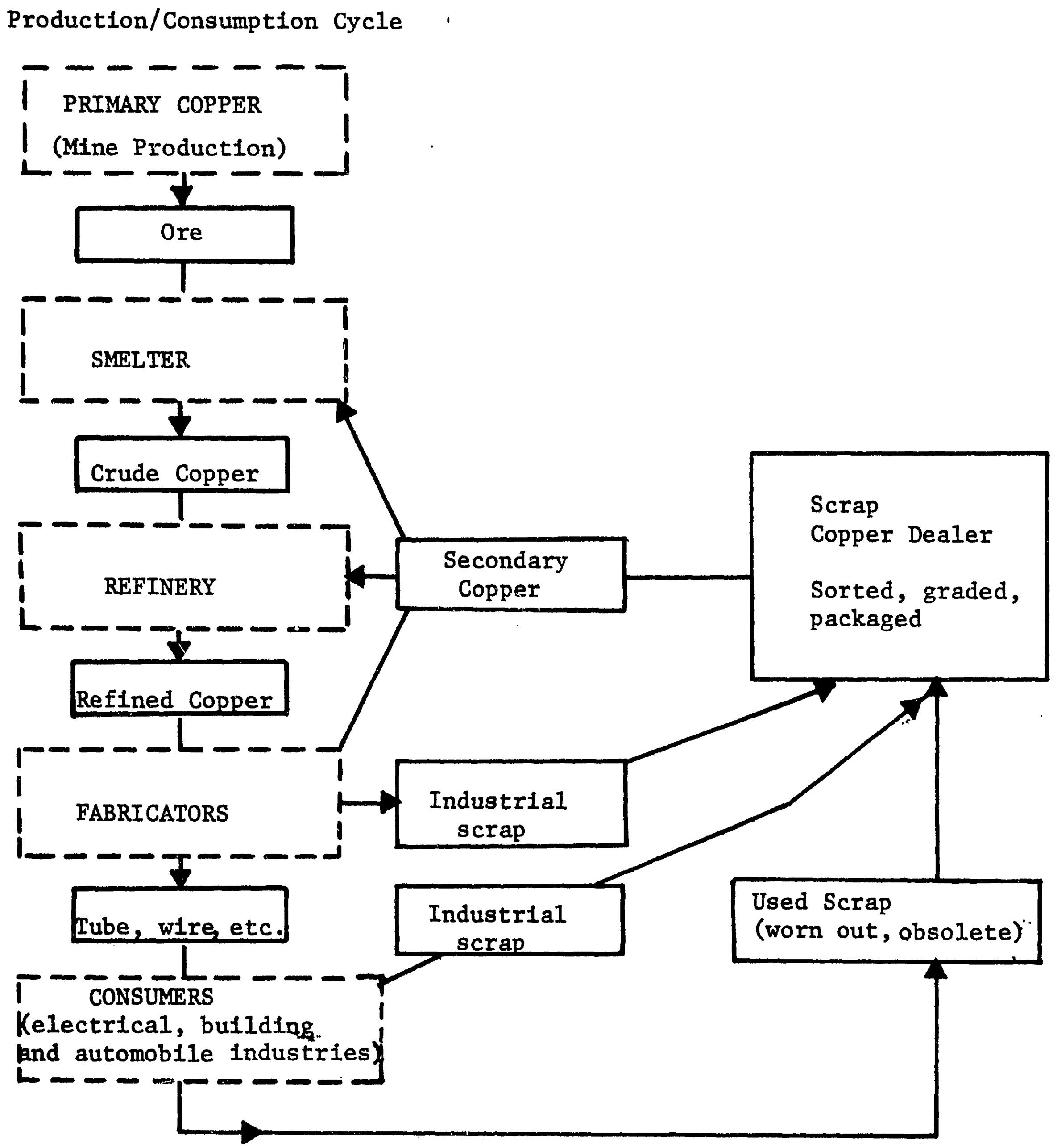
The short-run inelasticity of copper supply and demand with respect to price highlight the importance of harmonising copper mine capacity expansions with demand growth if mines are to remain viable. An indicator of the feasibility of any mine capacity expansion is the maintenance of a viable mine capacity utilization rate. The decline in North American mine capacity utilization rates from 95% in the early 1960s to only 65% in the early 1980s thus reflects the declining viability of North American mines. This resulted from capacity expansions of domestic mines with falling ore grades during a period when foreign supplies were becoming more competitive and North American copper imports were rising. In contrast, other producing countries have, despite mine capacity expansions, continued to maintain capacity utilization rates of about 85-90%.

3.5 The Secondary Supply of Copper

A secondary source of metal supply is the scrap generated from previous metal consumption. Scrap supply affects primary supply via the relative costs of production, and affects the demand for primary metal via its substitutability with the primary metal. Generally speaking, the technology for recovering metal from scrap material is far simpler than that of winning metal from ore. The simpler technology provides for relatively easy entry into the scrap industry, leading to the scrap market being typically more competitive than the primary market. Not all secondary materials smelted from scrap are perfect substitutes for primary metal so that the degree of material substitutability of secondary for primary material determines the degree of importance of the scrap industry. Since copper scrap is a perfect substitute for the primary metal (refined from the ore), the secondary copper industry plays an important role in the copper market.

In dealing with scrap, it is important to distinguish new (or industrial) from old scrap. These two types of scrap are critically different in nature--a difference which stems from the point of their occurrence along the processing and industrial manufacturing chain. This point is illustrated in Figure 3.1 (adopted from

Figure 3.1: OCCURRENCE OF SECONDARY COPPER IN THE COPPER PROCESSING MANUFACTURING CHAIN



SOURCE: BRISK (1979).

Brisk, 1979:8) which shows the points along the production and consumption cycles from which the two types of scrap are derived. 1/

The secondary supply of copper constitutes about one-third of all copper supply. Of this secondary supply, two-fifths derive from old scrap copper. For the purposes of the model, only old scrap is considered since it is this scrap that has an impact on primary copper production. Furthermore, given the short-run price inelasticity of primary copper supply, the availability of old scrap copper becomes a significant factor in the short-run availability of all refined copper, and hence on refined copper price determination and on market stability.

Two features emphasized by Prain (1975:146) are the share of the market taken up by scrap supply and the short-run profit maximizing behavior of the old scrap suppliers. The latter is in contrast to the longer-run

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1/ New (or industrial) scrap comprises mainly defective semi-fabricated products and waste from the fabricating process (such as trimmings and stampings generated during the fabrication of copper goods). Thus new scrap is a fairly constant proportion of the refined copper consumed during any time period. The availability of old scrap supply is largely a consequence of copper's non-corrodibility. The stock of copper goods ("scrap reservoir") provides a source of scrap supply as copper products become worn-out or obsolete. The copper content is recovered through refining, as is the case with new scrap. In general, old scrap forms about one-third of all scrap supply. Supplies of old and new scrap are essentially different functions of time. While new scrap becomes available soon after the fabricating stage, old scrap becomes available only after it has been through the complete manufacturing-cum-durable goods consumption or obsolescence cycle.

Four types of scrap are generated from the two basic scrap materials: (1) Number 1 wire and heavy copper, (2) Number 2 wire, (3) yellow brass and (4) low-grade old scrap and residues. Number 1 wire and heavy copper scrap refers to new, unalloyed copper scrap that is clean and uncoated and is 99.9% pure. Number 2 wire is old scrap that is 92-96% pure copper, and includes unalloyed copper scrap that is relatively free from contaminants. Yellow brass old scrap includes copper base scrap of 65% copper-content. Lastly, and the least pure of all old scrap, is low-grade scrap and residues that may contain as little as 10% copper-content.

equilibrium pricing approach typical of primary producers. Another feature of the scrap market in the recent past is that the volume of old and new scrap in circulation is known to have been remarkably constant at about 40% of total consumption. Of this, one-third consists of old scrap. Given the profit-maximising behavior of scrap producers, scrap production is thus determined by the price and quantity of scrap produced as well as its production cost. Various stages are involved in the production of copper from scrap. 1/

3.6 Secondary Copper Supply Equations

As copper scrap is a perfect substitute in the demand of primary copper (even in international trade), scrap production is influenced by the

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1/ In general old scrap is collected in two ways. It is collected by individuals and sold to the scrap or junk yards from where it is centrally collected for recovery. Alternatively, scrap is collected by industrial users such as shipyards, railroads and the military who generate and accumulate old scrap from their capital goods consumption. Industrial users' scrap is typically sold directly to scrap dealers. In both methods of collection, scrap collection and recovery is a labor-intensive process.

In the preparation of scrap material for recovery, trained personnel test the quality of scrap received for sorting, cleaning, and packing. As scrap preparation is labor-intensive, preparation costs depend significantly upon labor costs. Capital costs are also defrayed to meet environmental regulations on pollution control and also for stockholding. Since most scrap dealers are small establishments with limited space and have weak links with financial institutions, dealer stockholdings of scrap are generally limited to about 30-days supply. Energy costs also play an important role in scrap recovery. The short-term impact of higher oil prices is to increase the scrap production costs. However, with the heat requirements for copper scrap production being one-third that of primary copper production, the long-run impact of higher oil prices should be to stimulate scrap recycling. In sum, labor, capital and energy input costs are important for the production costs of scrap. According to Brisk (1979), scrap can be converted into refined material at the relatively low cost of 3¢/lb to 6¢/lb. Since Number 2 scrap contains only 96% copper at most, the 4% waste must be accounted for in relating the value of a pound of scrap to that of cathode or wirebar. Thus after refining, a pound of Number 2 scrap will be worth 4% less than a pound of refined copper.

LME price of refined copper. The scrap price is therefore highly correlated with the refined copper price. However, given the short-run profit-maximizing behavior of scrap copper supply, an increase in demand tends to lead to a prompt increase in scrap supply, thereby dampening the rise in scrap price. Thus the increase in the scrap price tends to be proportionately less than the increase in the refined copper price. The converse holds in periods of low demand as scrap copper supply is curtailed more promptly than primary supply.

If it is assumed that the competitive supply of old scrap is influenced by scrap price expectations $E(P^{sc})$, subject to the constraint of the reservoir of obsolete and/or worn out equipment (SCRV) existing at any time period, the scrap supply (SCR) function can be written as:

$$SCR = f\ \{E(P^{sc}),\ SCRV\}$$

Since copper scrap refers here to the sum of all types of old scrap, each of which has its own price, the use of a single scrap price in the estimation would be inadequate. Given that scrap prices are correlated with the primary refined copper price, the LME price of refined copper may be used instead. Alternatively, in view of the asymmetrical response of scrap prices to LME price movements and the fact that scrap production responds relatively faster to market conditions than primary production, the level of stocks (STKEX) at the London Metal Exchange and New York Commodities Exchange (Comex) may be used to proxy market sentiments regarding the short-term demand for scrap.

For a proxy of the scrap reservoir variable (SCRV), Bonczare and Tilton (1975) have suggested compiling the cumulative net addition to the stock of copper consumed. However, their use of this variable gave insignificant estimates as was the case in this exercise. Therefore, the approach of approximating the reservoir directly by the refined copper consumption n years ago (CR_{-n}), with values of "n" ranging from 7 and upwards, was tried.

To reflect the energy cost constraint, the oil price was also included as an explanatory variable. The oil price was deflated by the consumer price index (CPI), introduced as a proxy for labor costs. The scrap production function can then be written as:

$$SCR = f\ \{STKEX,\ \ CR_{-n},\ P^{oil}/CPI\}$$

Using the above specification, separate scrap supply equations were estimated for the major scrap-producing countries; namely, the United States, the United Kingdom, the Federal Republic of Germany and Japan. In general, the use of the LME and Comex stocks variable gave consistently better estimates than when the LME price variable was used. It was found that the use of a 10-year lag on copper consumption gave consistently better estimates than other lags, except for the United Kingdom, where no significant lagged consumption estimator could be identified. Moreover, in the UK equations, the LME price variable was a better explanatory variable than the exchange stocks variable. Throughout all equations, the deflated oil price variable was insignificant.

While these results are interesting, the use of the above equations in the model would entail the specification and estimation of functions for stockholding behavior on the LME and Comex. To avoid this, an alternative specification of scrap supply was pursued. This specification is based on the notion of partial adjustment to the desired scrap supply, where the desired supply is a function of expected price. Using the extrapolative approach for formation of price expectations, scrap supply is then a function of current and lagged scrap price and lagged scrap supply.

Since the United States is the largest single producer of old scrap, and since Number 2 scrap is the dominant type of scrap supplied, the US Number 2 scrap price was used in estimating the equations for US and non-US scrap supply. For the non-US scrap supply, the lagged supply and price variables were insignificant explanatory variables. This may be the result of aggregating different scrap supplies in different regions. Instead, the trend variable, which proxies the growing scrap reservoir in the ROWW, was a significant estimator and was retained. The loglinear estimates for US and non-US scrap supply are presented in Table 3.4 from which can be seen that secondary copper supply has a short-run price elasticity of 0.57 and a long-run price elasticity of about 0.65. For non-US scrap supplies, the estimated short-run price elasticity is 0.36 and there is a secular growth of supply of 3% annually.

Before assessing the secondary supply outlook as a basis for the long-term projections, it is useful to present a brief survey of the structural changes that have occurred in the secondary copper market since the 1970s. The delineation of the key features are made use of later for analyzing alternative scenarios for secondary copper supply developments. With the main scrap reservoir located in the United States, this country has been the main scrap supplier and exporter throughout the post-WWII period--albeit with intervals of export control whenever shortages emerged in the domestic market. 1/

1/ These occurred in the periods 1955-57 and 1966-69. The latter episode arose when the effects of a strike in the US mining industry was exacerbated by increased demand because of the escalation of the Vietnam War.

TABLE 3.4: ESTIMATES OF SECONDARY SUPPLY EQUATIONS

Variable	Constant	P^{scrap}	P^{scrap}_{-1}	SCR_{-1}	Time	$\bar{R}^2$	DW	F
US Scrap Supply	0.58 (0.5)	0.57 (4.4)	-0.29 (-1.6)	0.57 (2.5)		0.66	1.92	$F_{3,10} = 9.55$
Non-US Scrap Supply	4.60 (12.1)	0.36 (4.7)			0.03 (5.1)	0.63	1.97	$F_{2,12} = 13.09$

Scrap export control measures were also used to reinforce the two-tier price system that was in force until 1978. The interdependence of US scrap copper exports and the US two-tier price system can be gleaned from the two periods of sharply-increased US scrap exports in the 1970s. In the period 1973-75 the US producer price was kept under control in an attempt to dampen the inflationary pressures on US industry. This price control led to a surge in scrap exports to Japan. When the US producer price system was dismantled in 1978, the US scrap price became more closely aligned with the LME price. The ability of foreign buyers to compete more effectively for US scrap led to another surge in US scrap exports in 1978-79.

Japan has been the major importer of US scrap copper since the 1950s. Despite its increasing copper consumption, a high proportion of Japanese manufactured goods has been exported, and scrap production has been limited. But in the 1960s Japan began to establish its concentrate-based smelting and refining industry, thereby reducing its dependence on scrap imports. Moreover, scrap imports had become increasingly less attractive as Japanese labor costs and pollution control costs rose. And increased vertical integration of the Japanese refineries with the copper semi-fabricating mills meant pressures to use primary refined copper produced within the group. As a result of these changes, by 1970 the gross weight of Japanese scrap imports from the United States was less than one-half the 1960 level. In 1978, scrap imports comprised 2.5% of total Japanese refined copper consumption.

Stricter pollution control measures and increasing labor costs in the United States and Western Europe meant that scrap users in these countries preferred clean scrap to minimize sorting costs and pollution-control costs. In contrast, newly-industrializing countries such as the Republic of Korea (where labor costs are lower and pollution controls less stringent) began competing for the lower-grade scrap material. The domestic pricing structure in the Republic of Korea, which imposed higher tariffs on imported refined copper products than on scrap, provided added incentive to import scrap and to sell the resultant secondary refined copper at higher than world prices.

Since the mid-1970s the global availability of scrap, especially Number 2 (old) scrap, has declined. The low prices during the economic downturn since the mid-1970s have reduced the incentive for scrap dealers to collect and sell old scrap material. The declining availability of Number 2 scrap also stems from the growing competition for Number 1 (industrial) scrap, and the rise in production cost for Number 2 scrap. With the slowdown in economic activity, less Number 1 industrial scrap is available for direct smelting. This has heightened the competition for Number 1 scrap and made the upgrading of Number 2 scrap to Number 1 specifications increasingly attractive. Consequently, the spread between the Numbers 1 and 2 scrap prices has widened. This widening of the price spread was supported by the increase in refining costs. The decline in the general availability of scrap has also been caused by material substitution over time in items such as kettles, potboilers, and gutters. Such substitution has made inroads into the potential supply of light copper scrap having 92% copper content.

Technological progress has also facilitated the upgrading of Number 2 to Number 1 scrap through the introduction of <u>choppers</u>. These choppers or chopping systems were designed to separate the insulation material from the spent wire and to minimize the pollution that is generated when wires are burned to remove insulation. Choppers are now the predominant method of cleaning spent wires for scrap copper.

The increase in Number 2 scrap processing costs has affected the profitability of scrap production, and made the "dump-picking" mode of scrap collection less attractive. With the gradual disappearance of small-scale scrap collectors, the volume of collected material as a proportion of potentially salvageable copper scrap has been declining. Thus for an equal volume of scrap collection, an increase in scrap prices over time would be necessary.

3.7 Refined Copper Supply Equations

Although mine production (of ores and concentrates) equations for the major producing countries have been estimated, the production of primary refined copper for each country does not necessarily correspond to their mine production because of the international trade in ores and concentrates. Refined copper is produced even in some non-copper producing countries. Thus, in analyzing primary refined copper supply, it was decided to treat the United States separately because it is simultaneously a major producer and consumer. For the remaining market economies the total refined copper supply has been estimated aggregatively from the total non-US mine output. Primary refined copper production is derived as a function of mine output and the refined copper price. In addition, producers' stockholdings may play a role in determining the rate of refining ores and concentrates. Hence, the primary refined copper supply for any country/region can be written as

$$QREF1 = f\{Q, P, PSTK\}$$

where QREF1 is the primary refined copper production;

Q is the mine production of ores and concentrates;

P is the price of refined copper;

and PSTK is the producers' stocks of refined copper.

In estimating the US primary refined copper production, the US net imports of ores and concentrates (NMOCUSA) are introduced since this is an additional source of material for refining. Instead of single-period producers' stocks, the 2-year moving average of producers' stocks (AVPSTKUSA) in the United States was used. The estimated equation for US primary refined copper production is

$$\begin{aligned} QREFUSA1 = \underset{(2.1)}{329.25} + \underset{(8.0)}{0.83}\ QUSA + \underset{(1.9)}{0.35}\ NMOCUSA \\ \underset{(-2.2)}{-0.52}\ AVPSTKUSA \end{aligned}$$

$\bar{R}^2 = 0.883$; $DW = 1.65$; $F_{3,\ 11} = 36.27$;

Although the US domestic producers' price was also included as an explanatory variable, it failed to give significant estimates with the expected (positive) sign and was excluded.

The total refined copper supply for the United States, defined as the sum of primary and scrap supply, is given by:

$$QREFUSA = QREFUSA1 + SCRUSA$$

where QREFUSA is the total refined copper supply;

QREFUSA1 is the primary refined copper supply;

and SCRUSA is the secondary refined copper supply from old scrap.

For the remaining market economies, PSTK (current and/or lagged) failed to yield significant estimates. The primary refined copper supply equation is instead estimated with lagged refined copper production and given by:

$$\ln QREFROWW1 = \underset{(-3.1)}{-0.62} + \underset{(8.8)}{0.87} \ln QWWORNUSA + \underset{(2.3)}{0.19} \ln QREFROWW1(-1)$$

$$\bar{R}^2 = 0.99; \qquad DW = 1.58; \qquad F_{2,15} = 1597.30$$

where QWWORNUSA is the mine production of the non-US market economies. Similar to the results for the US equation, primary refined copper supply in non-US regions was found to be price inelastic.

The total refined copper supply of the non-US market economies is the sum of primary refined copper production and secondary refined copper from old scrap. That is:

QREFROWW = QREFROWW1 + SCRWWOR

where SCRWWOR is the secondary copper production of the Western World, excluding the United States.

IV. COPPER TRADE OF THE UNITED STATES AND COMECON COUNTRIES

4.1 Reasons for Partial Analysis of Trade in Copper

Although the model of the copper market in the Western world (namely the market economies and China) which is presented here essentially focusses on supply and demand, equations for the copper trade of the United States and Comecon are included--albeit for different reasons.

The inclusion of separate equations for US net imports of refined and unrefined copper serve to explain the changing position of the United States in the world copper market. Inclusion of these equations allows implicit analysis of the comparative advantage of the US copper industry vis-a-vis that of the rest-of-the-world. The net imports equations are also necessary to allow estimation of the total net imports influencing the level of domestic production in the United States.

Since net imports from the Comecon countries affect supplies on the world market, they influence the LME price. Introduction of a Comecon net imports equation allows them to be treated endogenously and to be forecast.

4.2 The United States as a Net Importer of Copper

To understand the behavior of the US producer's price it is essential to analyze changes in the US copper trade. Any such analysis should be conducted within the context of the political and structural changes which have occurred in the main developing-country producers and their subsequent shift to direct trading with prices based on LME quotations.

During the time US producers were supplying copper under a unified list price structure, this largest single producing country (up to 1982, when it was surpassed by Chile) was also a major trader with a net importing position of increasing importance. However, the composition of US imports changed (from copper ores and concentrates to refined copper) during this period. Table 4.1 gives the composition of US net copper imports for selected years during the 1960-84 period. In 1960, for example, the United States was the world's leading refined copper exporter. By 1972 it had become a net importer of refined copper (refined copper imports were abnormally high in 1967 and 1968 when the US copper industry was severely hit by strikes). Although the United States was still exporting refined copper in 1975, the volume was significantly smaller than in 1965. The year 1975 may also be viewed as a watershed for the US net refined copper trade because of the positive net refined copper imports thereafter--imports increased from 245,000 tons in 1976 to as high as 440,000 tons in 1980.

The decline in competitiveness of US producers can be attributed to declining ore grades and increases in labor costs and refining costs (due to the increasingly-stringent environmental regulations). Furthermore, as foreign producers have extended their nationalized operations to include copper refining, exports of ores and concentrates have become less readily available. It is posited here that US net imports are influenced by the difference between US and world prices (this difference being exacerbated by the strong US dollar in the early 1980s) and by a trend variable proxying the decline in the supply of ores and concentrates from US-owned mines abroad. Separate equations are estimated for US net imports of refined and unrefined copper. The function for US net imports of ores and concentrates can be written as:

NMOCUSA = f {PDIFF/CPIUSA, TIME}

where PDIFF/CPIUSA is the difference between the US producers' price and the LME price, deflated by the US consumer price index.

and TIME is the trend variable to proxy the fall in ores and concentrate supply from US-owned mines abroad.

In the period before the 1970s the United States largely exported refined copper, with the exception of some years (as in 1968) when there was a prolonged strike in the domestic industry. Since refined copper was also imported in the earlier periods to fill the shortfall between consumption and

TABLE 4.1: COMPOSITION OF US NET IMPORTS OF COPPER FOR SELECTED YEARS, 1960-1984 ('000 tons)

Year	Refined Copper	Copper Blister	Copper Ores and Concentrates	Total
1960	-265.2	266.8	63.0	64.6
1965	-175.5	297.3	23.8	145.6
1967*	151.2	224.7	-4.8	371.1
1968*	135.4	231.0	-28.1	338.3
1970	-81.5	196.4	-25.5	89.4
1972	9.6	134.8	33.9	178.3
1975	-25.8	77.6	61.3	113.1
1976	244.9	37.9	68.1	350.9
1977	298.5	27.0	29.5	355.0
1978	319.4	68.3	14.1	401.8
1979	140.3	60.6	-9.6	191.3
1980	439.2	44.1	-78.6	404.7
1981	299.0	65.8	-96.1	268.4
1982	253.0	104.2	-84.6	272.8
1983	401.0	74.6	66.5	542.1
1984P	408.0	51.8	-25.4	434.4

Source: World Bureau of Metal Statistics.

Notes: *Years of strikes in the United States.
P = Preliminary figures.

domestic production of refined copper, a variable measuring this shortfall (CQDIFF) has been included as an explanatory variable in the US net imports of refined copper function which can then be written as:

NMRUSA = f {CQDIFF, PDIFF/CPIUS, POIL/CPIUS}

where CQDIFF is the shortfall between consumption and domestic production of refined copper;

PDIFF/CPIUS is the differential between the domestic producers' price and the LME price, deflated by the US consumer price index;

and POIL is the price of oil, deflated by the US consumer price index.

Although the PDIFF/CPIUS variable appears in both the refined and unrefined copper imports equations, it has opposite influences in the determination of these net import levels. Net imports of unrefined copper should be negatively related to the deflated price differential, while net imports of refined copper should be positively related. The estimation results for the two net imports equations for the 1965-83 period are:

$$\underset{}{NMOCUSA} = \underset{(4.3)}{337.81} - \underset{(-2.8)}{7.50}\ PDIFF/CPIUSA - \underset{(-3.0)}{8.88}\ TIME - \underset{(-2.1)}{100.54}\ DV1980$$

$\bar{R}^2 = 0.82$; DW = 1.84; $F_{3,15} = 28.65$;

$$NMRUSA = \underset{(-1.1)}{-43.48} + \underset{(4.9)}{0.50}\ CQDIFF + \underset{(4.9)}{10.60}\ POIL/CPIUSA + \underset{(12.1)}{7.22}\ PDIFF/CIPUSA$$

$\bar{R}^2 = 0.84$; DW = 2.26; $F_{3,15} = 33.51$;

The estimates for the PDIFF/CPIUS variable in the two equations have opposite signs, as expected. Net imports of unrefined copper are reduced as the domestic producers' price increases relative to the world price--since this makes domestic mine production more profitable. Conversely, as the domestic producers' price for refined copper rises relative to the world price, consumers--especially those fabricators which are not vertically-integrated with the copper mining companies--find it profitable to import refined copper.

The trend variable in the unrefined copper equation has the expected negative sign consistent with the decline of unrefined copper imports. DV1980 is a dummy variable to account for the sharp drop in net imports in 1980, a drop which is greater than can be explained by the price differential.

In the equation for net imports of refined copper, the coefficient on the domestic production shortfall variable (CQDIFF) has the expected positive sign, substantiating the argument that such imports have compensated for the periodic shortages observed in the domestic market. The PDIFF/CPIUS coefficient is positive, indicating that more refined copper will be imported as the price differential widens. Higher energy costs stimulate net refined copper imports, as seen by the positive coefficient on the deflated energy price variable POIL/CPIUSA.

Total net imports of refined and unrefined copper (NMUSA), which is an explanatory variable in the equation explaining US mine production, is the sum of the net imports of both refined and unrefined copper.

4.3 The Net Exports of Comecon Countries

Two approaches have been used to include Comecon net exports in the model. One approach exogenises these net exports on the assumption that the determination of Comecon trade in general, and its copper exports in particular, is too complicated an issue to be adequately treated here. Alternatively, it can be assumed that regardless of how intra-Comecon trade is determined, exports by the Comecon countries are made principally for their foreign exchange earnings. These net exports can then be hypothesized as being determined by the level of world prices as quoted in the London market. The level of net exports in the previous year has been introduced as a variable constraining sharp increases in net exports between consecutive years. The function for Comecon net exports (NXCOMECON) can be written as

$$NXCOMECON = f\ \{PLME,\ NXCOMECON_{-1}\}$$

where PLME is the LME price quotation, given in pounds sterling per metric ton.

The estimated equation for net copper exports from the Comecon countries over the period 1965 to 1983 is presented below.

$$NXCOMECON = \underset{(-2.61)}{-82.47} + \underset{(3.1)}{0.16}\ PLME + \underset{(2.4)}{0.40}\ NXCOMECON_{-1}$$

$$\bar{R}^2 = 0.82; \qquad DW = 1.84; \qquad F_{3,15} = 28.65;$$

V. STOCKHOLDINGS AND PRICE FORMATION

5.1 The Key Issues

Up to 1978, the global copper market was characterized by a two-tier price system consisting of a US domestic producers' price that was at times significantly different from the world price as quoted on the London and New York exchanges. Although various hypotheses have been postulated to explain the US domestic producers' pricing behavior, tests for these hypotheses have been inconclusive (NcNicol, 1975).

While the issue of the two-tier price system is interesting, this study of the recent 1968-1983 period does not focus on it. The focus is on the determination of the copper price as quoted on the LME, bearing in mind the long-term forecasting purposes of the model. The premise for taking the LME price as the world reference price is that it is the leading exchange price adopted by the trade. In the period under study the US domestic producers' price has therefore been specified as a function of the LME price.

To understand price formation it is necessary to analyze stock movements and the demand for stocks by different groups in the market. In the following sections, the motives for stockholding are first discussed. The equations for the LME price and the US domestic producers' price are set out, as well as equations for certain categories of stockholding. Finally, there is a discussion of the published stock data.

5.2 Transactions, Precautionary and Speculative Stockholding

Table 5.1 describes the imbalances between primary mine production and refined copper consumption in the market economies during the 1960-83 period. These imbalances invoke questions about the role of stocks and secondary copper supply in the price formation process. The markets for primary commodities with industrial end-uses are usually characterized by two features: (1) the geographic distance between the consuming and producing regions, and (2) cyclical demand, which is related in part to the business cycle. A consequence of the geographic distance between producers and consumers is the supply of storage (or demand for stockholding) for its convenience yield. When a commodity is traded on a commodity exchange with the participation of traders and commission houses, the physical trade generally becomes complicated by the hedging and speculative activities which lead to stockholding to support the paper trade. For example, in order to understand the price formation process at the London and New York commodity exchanges, it is necessary to understand the raison d'etre for the variously owned and differently-located stockholdings.

Basically, three groups of refined copper stockholdings can be distinguished. These are (1) producers' stocks, (2) consumers' stocks and (3) stocks at the LME and Comex warehouses. (In addition, strategic stockpiles have been held by the US and Japanese governments.) The influence of these stockholdings on price formation is complicated by the fact that to minimize production disruptions due to bottlenecks, stocks of copper semi-fabricates (intermediate copper goods) are also held at various stages in the processing chain. The stockholdings of semi-fabricates complicate primary price formation since their determinants interact with the price expectations for primary refined copper, and hence with the levels of the variously-owned stocks.

As the bulk of refined copper is traded under contracts, typically of one year duration, producers' stockholdings are motivated primarily by considerations of supply management--to meet the shipments specified by the contracts. In countries where strikes by mineworkers are periodic, producers'

TABLE 5.1: IMPLICIT REFINED COPPER STOCKS AND OLD AND NEW SCRAP MOVEMENTS DERIVED FROM PRODUCTION-CONSUMPTION IMBALANCES IN THE MARKET ECONOMIES ('000 TONS)

Year	Production	Consumption	Imbalance
1960	3614	3984	-370.0 (10.2)
1965	4162	5199	-1037.0 (25.0)
1970	5274	6044	-770.0 (14.6)
1975	5843	5717	+126.0 (2.2)
1980	6266	7418	-1152.0 (18.4)
1981	6746	7572	-826.0 (12.2)
1982	6525	7148	-623.0 (9.6)
1983	6465	7151	-686.0 (10.6)

Note: Figures within parentheses refer to percentages of the production in the same year.

stockholdings may also be made in anticipation of strikes, as is the case in the United States. Producers' stockholdings may therefore be regarded as stockholdings for transactions purposes. In periods of a fall in demand, stocks are also held because it is too expensive to close the mines. Although some producers may hold stocks for speculative purposes, this activity is likely to be minimal in the developing countries because of the distances from the consuming regions and their relative lack of financial market know-how.

Consumers' stocks are held chiefly for the precautionary motive of ensuring a smooth supply of refined copper. In a situation of market tightening, some stocks are also held in anticipation of price increases, or supply shortfalls.

Besides producers' and consumers' stocks, significant volumes of stocks are also held in the LME and Comex warehouses for transaction and speculative reasons. In general, these stocks belong to traders and agents who, as intermediaries between the producers and consumers, are likely to be best informed on the market situation. Given their vantage point and wider access to financing facilities, it is not surprising that agents and commission houses would generally be more actively involved in speculative and hedging activities than would producers and consumers.

Exchange rate fluctuations extend the scope for hedging and speculative activities from that based on copper to that of exchange rate futures. Given the delivery lags due to the distance between the producing and consuming regions, the influence of speculative and hedging activities by agents on copper price formation *per se* is also critically dependent on the distribution and timing of the copper shipments from the production source. This is especially pertinent to the terminal markets where there are no domestic supplies to call upon.

5.3 Specification of the Price Equations

The LME price quotation is taken to be the world indicator or reference price, and is assumed to dictate copper price quotations on other markets. For instance, arbitrage between the London and New York markets reinforces the link between the Comex and LME prices while the US domestic producers' price is subject, eventually, to the influence of the Comex price.

5.3.1 The LME Price

The specification of the LME price determination function is dictated by two features of the copper market. These are the predominance of supply contracts of one year or longer (drawn up in the autumn of each year) and the distance between the consuming and producing countries. Most contracts specify shipment schedules and price clauses that are related to the LME price.

During the period of the contract occasional supply shortfalls, due perhaps to unanticipated increases in demand, may be envisaged. The likelihood of shortfalls gives rise to the need for stockholdings in the consuming regions and perhaps for a nearby market to which consumers can resort for their unanticipated additional requirements. The LME and the Comex serve this purpose and are generally considered to be the marginal markets for the physical trade. By being suppliers of the last resort in a sense, the LME and Comex trading positions thus serve as barometers of the market situation and sentiment. The LME price formation process can thus be interpreted as a tatônnement reflecting adjustment towards equilibrium demand for copper stocks.

Suppose observed stockholdings are the result of partial adjustment to a desired level of stockholdings S*, and S* is given by

$$S_t^* - S_t = \lambda\,(S_t^* - S_{t-1}^*)$$

Then

$$S_t^* = \left(\frac{1}{1-\lambda}\right) \{S_t - \left(\frac{\lambda}{1-\lambda}\right) S_{t-1} + \left(\frac{\lambda}{1-\lambda}\right)^2 S_{t-2} - \left(\frac{\lambda}{1-\lambda}\right)^3 S_{t-3} + \ldots\}$$

where λ is the rate of adjustment to the desired stocks in each period. S^* is the sum of stocks which the market desires to hold for transactions and speculative purposes. It is assumed that producers' and consumers' transactions stocks are determined by Western world refined copper production (QRWW) and consumption (CRWW) respectively, while speculative stockholdings are influenced by expectations regarding the copper price (P^*) and interest rates (INT^*) . Hence

$$S^* = f\ \{P^*,\ QRWW,\ CRWW,\ INT^*\}$$

Substituting S^* as a function of S into the expression for S^* and re-arranging terms gives

$$S = f\ \{S_{-1},\ S_{-2},\ QRWW,\ CRWW,\ P^*,\ INT^*\}$$

Normalizing on the price variable then gives

$$P^* = f\ \{S\ ,\ S_{-1},\ S_{-2}\ QRWW,\ CRWW,\ INT^*\}$$

Using the extrapolative model for the formation of price expectations, the spot price in any period becomes a function of lagged prices. Hence, price in any period can be specified as

$$P = f\ \{S,\ S_{-1},\ S_{-2},\ QRWW,\ CRWW,\ INT^*_{-1},\ P_{-1},\ P_{-2}\}$$

Given the relatively short estimation period (1968-1983), the explanatory variables were rearranged for maximum degrees of freedom. For all flow variables, data for the period t refers to the cumulative total for the period. However, data for stocks refer to the stock levels at the <u>end</u> of the period. For example, data for 1980 stocks refer to stocks held on 31st December of 1980. From the perspective of the demand for stocks, the stock level at end 1980 (or beginning 1981) is that which will interact with production and consumption during 1981 and influence the average 1981 price. Thus the stock variables $\{S, S_{-1}, S_{-2},\}$ in the price function above become $\{S_{-1}, S_{-2}\ S_{-3}\}$. Given that stocks in the near term have greater bearing on current period price formation than stockholdings in previous periods, and given the degree of freedom factor in regression analysis, a more efficient representation of $\{S_{-1}, S_{-2}, S_{-3}\}$ is $\{S_{-1}, \Delta S_{-2}\}$, where $\Delta S_{-2} = S_{-2} - S_{-3}$.

The impact of production and consumption on price can be expressed as the ratio of consumption to production, to reflect the pressure from the consumption-production imbalance. Thus, the price function can be rewritten with two fewer independent variables as:

$$P = f\ \{S_{-1}, \Delta S_{-2}, \frac{CRWW,}{QRWW,} P_{-1}, P_{-2}, INT^{*}\}$$

Two "extraneous" factors need to be considered in the price equation: (i) the net exports of the Comecon countries (NX), and (ii) the releases (or accumulation) of government stockpiles (DG). Net exports of the Comecon countries are "extraneous" in that while it would be reasonable to assume and/or hypothesize that Comecon exports are influenced by the LME price, little is known about how the level of exports to the market economies vis-a-vis intra-Comecon exports is determined. Government stockpile changes may be influenced by the LME price or by non-price decisions such as the perception that supply security is no longer pertinent. Since Comecon net exports and government stockpile accumulation/releases affect the total availability of copper in the market economies, they are added to the production variable (QRWW). The (CRWW/QRWW) variable becomes (CRWW/QRWW+NX+DG).

The price formation function presented is specified in terms of the demand for copper for consumption and stockholding. Hence, the specification may be viewed as capturing the influence of the "real" physical demand factors on price determination. However, the recent experience of floating exchange rates raises the question of the extent to which commodity price variations may be attributable to exchange rate variations. In the case of copper, which has sometimes been referred to as a "sterling commodity" in view of its long history of trade in £ -sterling on the LME, the question becomes more specifically the extent to which exchange rate variations affect the sterling price level. To test for the influence of exchange rate variations, the price formation function was modified by introducing the real exchange rate between the pound and the US dollar (RR1UK).

The real exchange rate RR1UK is computed from the formula:

$$RR1UK = \sum_{i=1}^{N} w_i \left(\frac{e^{UK}/p^{UK}}{e_i/p_i}\right)$$

where e is the nominal exchange rate against the US dollar;

p is the consumer price index;

i is the country i included as one of the major trading partners of the United Kingdom; 1/

1/ Countries included in the computation of RR1UK are the United States, Canada, Australia, Japan, New Zealand, Austria, Belgium, Denmark, Finland, France, the Federal Republic of Germany, Iceland, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, Iran, Nigeria, Saudi Arabia, Venezuela, Côte d'Ivoire, Kenya, Mauritius, Morocco, South Africa, Tanzania, Zaire, Zambia, Hongkong, India, Korea, Malaysia, the Philippines, Singapore, Sri Lanka, Thailand, Cyprus, Greece, Malta, Portugal, Turkey, Yugoslavia, Egypt, Israel, Argentina, Brazil, Chile, Colombia, Dominican Republic, Ecuador, El Salvador, Guyana, Jamaica, Mexico, Trinidad and Tobago.

and w_i is country i's share of the total UK imports and exports.

The copper price will also be influenced by general inflationary trends. Given that copper is consumed largely in the OECD industrialized countries, the GDP deflator for the OECD countries (DEFOECD) was used as the indicator of the general inflation rate. The remaining variable to be defined is the interest rate. The real London Inter-Bank Offer Rate (LIBOR) was used after adjusting the LIBOR by the rate of change of the GDP deflator for the OECD countries.

In estimating the price equation, it was found that one-period lagged total stocks, the consumption-production ratio, the real exchange rate and the OECD GDP deflator were significant. Lagged prices and real interest rates were found to be statistically insignificant. The estimated equation selected for the model is:

$$\underset{}{\text{PLME1UK}} = \underset{(-3.5)}{-3122.5859} - \underset{(-3.5)}{0.3693}\ \text{TOTSTKJUX}_{-1} + \underset{(3.9)}{15.0734}\ \text{RR1UK}$$

$$+ \underset{(3.2)}{1524.8933}\ (\text{CRWW/QRWW+NX+DG}) + \underset{(6.4)}{13.0214}\ \text{DEFOECD}$$

$\bar{R}^2 = 0.821$; DW = 1.97; $F_{4,13} = 20.453$;

where TOTSTKJUX is the total stocks at the end of the period; 1/

CRWW/QRWW+NX+DG is the ratio of refined copper consumption to total refined copper available in the market economies and China;

1/ For details on the problems with published data for total stocks, see Section 5.4 of this Chapter.

and PLME1UK is the LME price of copper quoted in pounds per ton.

The estimates for the price equation indicate that during the 1966-83 period, the LME price in pounds per ton was influenced more by the current period's copper availability in the market economies than by the level of ending stocks in the preceding period. A 1% increase in the ending-stocks level would cause a 0.5% fall in price in the following period. But 1% excess demand would precipitate a 2.2% increase in the nominal price. This excess demand response is marginally higher than the value of 1.8% estimated by Koss (1985) for the 1960-1982 period.

The estimated coefficient for the real exchange rate variable indicates that a 1% decline in the value of the pound vis-a-vis the dollar (i.e., an increase in the pound-dollar exchange rate) would result in a 2.5% increase in the LME pound sterling price quotation for copper. While this elasticity may seem unduly high, Gilbert (1986) in his study of the impact of exchange rates and developing country debt on commodity prices obtained price elasticities of similar magnitudes. Gilbert suggests an explanation for this high elasticity by invoking the debt problem of the developing primary commodity producing countries. He argues that given a US dollar price decline for a commodity, the debt servicing requirements of the exporting countries force these countries to respond by increasing their exports of the commodity so as to maintain their export revenues and thus service the debt. The rise in commodity exports causes a further fall in the dollar price of the commodity so that the total impact is a fall in price by more than the rate of the dollar depreciation.

The estimate for the OECD deflator suggests that a 1% rise (fall) in inflation in the OECD countries would allow the LME copper price to rise (fall) by 1.3%. This result suggests "money illusion". However, another rationale for this kind of result is that metals commodities such as copper act as a hedge in an inflationary period.

5.3.2 The US Producers' Price

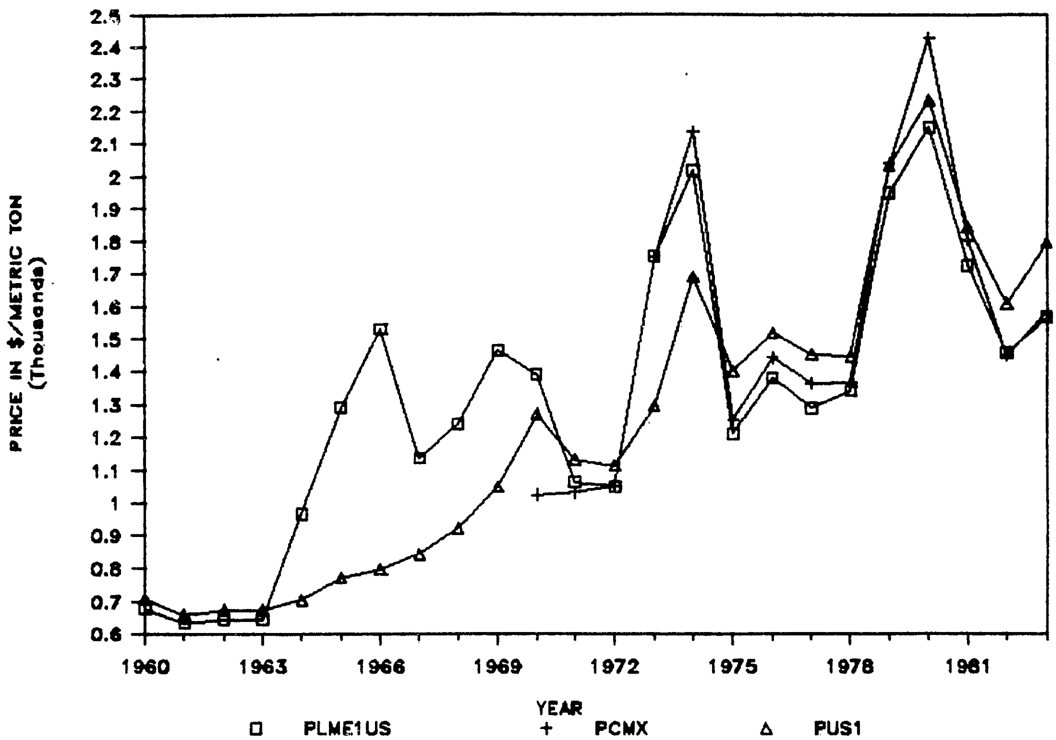
Up to the mid-1960s, when the United States was the dominant producer and consumer, the US copper industry was loosely oligopolistic; producers were operating under a unified price structure known as the domestic producers' price. In effect, this was a list price since price discounting was known to occur. Internationally, the US position as a consumer was reflected in its being a net importer of unrefined copper (ores and concentrates and blisters) and exporting some refined copper at the world price. However, nationalization in the mid-1960s of the copper industries in some copper-producing developing countries as well as increased exports of refined copper from the developing countries by independent merchants presented the US consumers with cheaper materials. By 1973 the cumulative effect of this material availability changed the trade status of the United States from that of an exporter to an importer of refined copper, and the competitive forces continued to pressure the viability of the US domestic pricing structure.

In an attempt to compete with the independent traders for the domestic market, the US producers followed the initiative of Kennecott in late 1978 and switched to pricing based explicitly on the Comex price quotation (which is closely related to the LME price). Consequently, the producers' price became quoted on the basis of the Comex price plus a premium. Although the US competitive position in the world market had eroded before then, it was not until 1978 that the producers' pricing formula was modified. 1/ The timing of this change, in spite of the pressures being felt since 1973, might have been due to uncertainties in the world economy that were precipitated by the adoption of the floating exchange rate regime and the quadrupling of the oil price in the early 1970s. In addition, the delay may be explained by the fact that from the early 1960s to 1975, the US producers' price was consistently lower than the Comex price. But after 1975 the US producers' price was occasionally higher than the Comex price as Figure 5.1 shows. This premium probably exacerbated the rising trend of refined copper imports into the United States from the mid-1970s.

An analysis of the various price series shows that the premium which the US domestic producers were adding onto the Comex price since the mid-1970s was based on the observed trend deviations of producers' price from the Comex price which became available only from 1970 onwards. The determination of the US producers' price after 1970 was therefore influenced by the Comex price and the domestic market situation. Since the Comex price is closely related to the LME price, the US producers' price was ultimately determined by the LME price.

1/ In 1978, Comex also introduced the price of higher-grade cathodes as a reference price. This innovation was due to the development of the continuous casting technique which permits the direct casting of wire-rods from cathodes, thus bypassing the intermediate stage of wirebar production. As the preference now is for higher-grade cathodes instead of wirebars, the cathode price has been able so far to maintain a premium over the wirebar price. But this premium is expected to disappear over time. In this connection, it should be mentioned that the LME did not adopt higher-grade cathode pricing until 1981. This may be due to the almost century-long tradition of wire bar trading on the LME and the fact that until recently, continuous casting was not very widely applied outside the United States.

FIGURE 5.1: TIME PATHS OF LME, COMEX AND US PRODUCERS' PRICE FOR COPPER, 1960-1983 ($/METRIC TON)



YEAR	PLME1US	PCMX	PUS1
1960	678		707
1961	633		660
1962	645		675
1963	646		675
1964	967		705
1965	1290		772
1966	1530		797
1967	1136		843
1968	1241		923
1969	1466		1048
1970	1392	1025	1272
1971	1064	1033	1134
1972	1052	1053	1116
1973	1753	1752	1298
1974	2019	2137	1690
1975	1212	1251	1401
1976	1380	1441	1517
1977	1289	1364	1451
1978	1340	1366	1444
1979	1951	2039	2034
1980	2152	2427	2236
1981	1725	1803	1846
1982	1458	1451	1607
1983	1566	1583	1795

In this study the focus is on the LME and US producers' prices only. The US domestic producers' price can therefore be explained as some function of the LME price (PLME) and the lagged US producers' price ($PUS1_{-1}$), all quoted in US dollars. That is:-

$$PUS1 = f\ \{PLME,\ PUS1_{-1}\}$$

The estimated equation is:-

$$\ln PUS1 = \underset{(-2.1)}{-1.73} + \underset{(4.4)}{0.52} \ln PLME1US + \underset{(9.9)}{0.72} \ln PUS1_{-1}$$

$$\bar{R}^2 = 0.91; \qquad DW = 1.80; \qquad F_{2,16} = 89.12$$

The estimates show the US domestic producers' price to be influenced more by the producers' price in the preceding period than by the LME price in the current period. While the domestic producers' price was slow to adjust, the estimates show that it was influenced by the LME price in the long run. During the 1965-1983 period, the US domestic producers' price tended to increase on average by 1.9% for every 1% rise in the LME price.

Since the estimation period is 1966-1983, and since the US producers' price was explicitly linked to the Comex (and hence LME) price only from 1978 onwards, the inadequacy of the estimated price equation above for forecasting purposes should be recognized. Instead of using dummy variables to capture the change in the pricing mechanism, an alternative price equation for the US producers' price is used for simulating the model in the post-1978 period. This equation is specified simply as 107% of the LME price, since the premiums applied to the US producers' price in the recent period have averaged around

7% of the LME price. Model simulation results, using the two different specifications of the US domestic producers' price, are discussed in Chapter VI.

The US Number 2 scrap price (PSC2USA) equation was estimated as a function of the US domestic producers' price (PUS1). Dummy variables were used to capture the price rises in 1969 (DV1969) as the Vietnam War escalated, and in 1973 and 1974 (DV7374) as oil prices quadrupled. The equation used in the model simulations is:

$$\underset{}{PSC2USA} = \underset{(1.1)}{80.70} + \underset{(15.7)}{0.71}\ PUS1 + \underset{(4.2)}{256.65}\ DV1969 + \underset{(8.4)}{346.31}\ DV7374$$

$\bar{R}^2 = 0.96$; $DW = 1.99$; $F_{3,\ 11} = 101.12$

5.4 The Stock Equations

The following sections present the specification of the US producer stocks equation, a discussion of the stocks data deficiencies, and a description of how the total stocks data used in the model are compiled.

5.4.1 US Producers' Stocks

In the United States, producers' stocks are a determinant of US refined copper production and a producers' stock equation is required for the model. In general, producers' stocks are held for transactions and precautionary reasons. Adopting the notion of partial adjustment to a desired level of stockholding, the producers' stockholding can be expressed as a function of producers' stockholdings in the past. Since desired stockholdings are determined by US refined copper consumption (CRUSA), the producers' stockholding function can be written as:

$$PSTKUSA = f\ \{CRUSA,\ PSTKUSA_{-1}\}$$

The above specification needs to be modified in light of the fact that producers' stockholding is influenced periodically by anticipations of mine-workers' strikes at the time of labor-contract negotiations. The bunching of producers' stocks that results from anticipation of labor strikes, and the increase in stocks immediately after sharp falls in stocks during strike years, are captured via a change in stocks variable lagged 3-periods; namely,

$$DPSTKUSA_{-3} = PSTKUSA_{-3} - PSTKUSA_{-4}.$$

The estimated producers' stockholding equation used in the model is:-

$$\underset{(2.1)}{PSTKUSA = 238.70} - \underset{(-1.9)}{0.11}\ CRUSA + \underset{(4.9)}{0.81}\ PSTKUSA_{-1} - \underset{(-1.4)}{0.33}\ DPSTKUSA_{-3}$$

$\bar{R}^2 = 0.62$; $DW = 1.96$; $F_{3,14} = 10.12$;

5.4.2 Deficiencies in the Stock Data

Empirical studies of the copper market have been plagued by the lack of reliable data on refined copper stocks. For example, there is a cumulative discrepancy in stocks data amounting to 1.2 million tonnes for the 1956-1978 period (see Copper Studies, 1978/10). Several reasons have been advanced for this discrepancy. These include lags in data reporting, random errors in data recording, relative degrees of improvement in data collection, double-entry due to ambiguity in differentiating production from consumption in the case of some intermediate copper goods, omission of data on imports and on consumption for ordnance and military purposes, the unreliability of data on scrap copper stocks and the definition of identifiable stocks and their coverage in the compilation of stocks data (Copper Studies, 1978/10). To these factors must be added the concealed accumulation of stocks during part of the historical period when producing countries attempted to stabilize prices. The last factor is taken into consideration in the decision not to approach stocks behavior from the viewpoint of their ownership, other than for the United States.

A common approach in overcoming the problem of discrepancies in the published stocks data is to derive the data series from a benchmark year as in Fisher et al. (1972) and Richard (1978). Alternatively, Radetzki (1977) suggests adjusting the published stocks data by first reconciling the observed inconsistency between the rates of change of refined copper consumption and industrial production. Bearing in mind the stocks data discrepancies, and the need for separating total stocks data and US producer stocks data, the approach adopted here in adjusting the published stocks data is eclectic. This consists of first harmonizing the various published stocks data in such a way that some of the stocks data by location can be used individually if necessary. Thus the approach entails developing an internally consistent data series for the entire period.

The data on refined copper stocks was extracted from various issues of World Metal Statistics (WMS) published by the World Bureau of Metal Statistics (WBMS). While this source provides the most detailed stocks data, some data inconsistencies are nonetheless present. For these reasons, some adjustments were necessary before the data were used in the empirical estimations. These adjustments were aimed at achieving overall data consistency and the method used was based on the quality of the published data.

Over the years, the WBMS has been continuously refining its data on stockholdings. In the 1960-66 period for example, only data for LME stocks and total stocks were available. Subsequently, separate data on Comex stocks became available in 1967. But separate data for consumers' stocks, producers' stocks and merchant stocks did not become available until after 1973. Over the years, the WBMS has also constantly revised its stocks data with each new bulletin. The most significant of such changes is the 1980 revision of the total stocks figure for 1974. In comparison with the figure of 832,000 tons quoted in various bulletins during 1978, the figure was revised upwards to 1,049,000 tons in the 1980 bulletins. By this revision, the difference in the total stocks situation between 1973 and 1974 was widened as Table 5.2 indicates. A check for the internal consistency of the 1973 data from the individual data series is not possible since the individual stocks series (by ownership) that make up total stocks are not available for the pre-1973 period.

Given the differential availability of the individual stocks series, and the marked change in total stocks between 1973 and 1974, it was decided to derive an alternative data series for total stocks for the 1967-1973 period. In choosing an estimation method, the method had to provide consistency between the total stocks and individually-owned stocks so that the individual stocks series for the 1960-1966 period can be backcast from the estimated total stocks series.

TABLE 5.2: VARIATIONS IN PUBLISHED STOCKS DATA
('000 tons)

Year	Pre-Revision	Post-Revision
1973	394.00	394.00
1974	832.00	1049.00
1975	1536.00	1743.00
1976	1672.00	1828.00

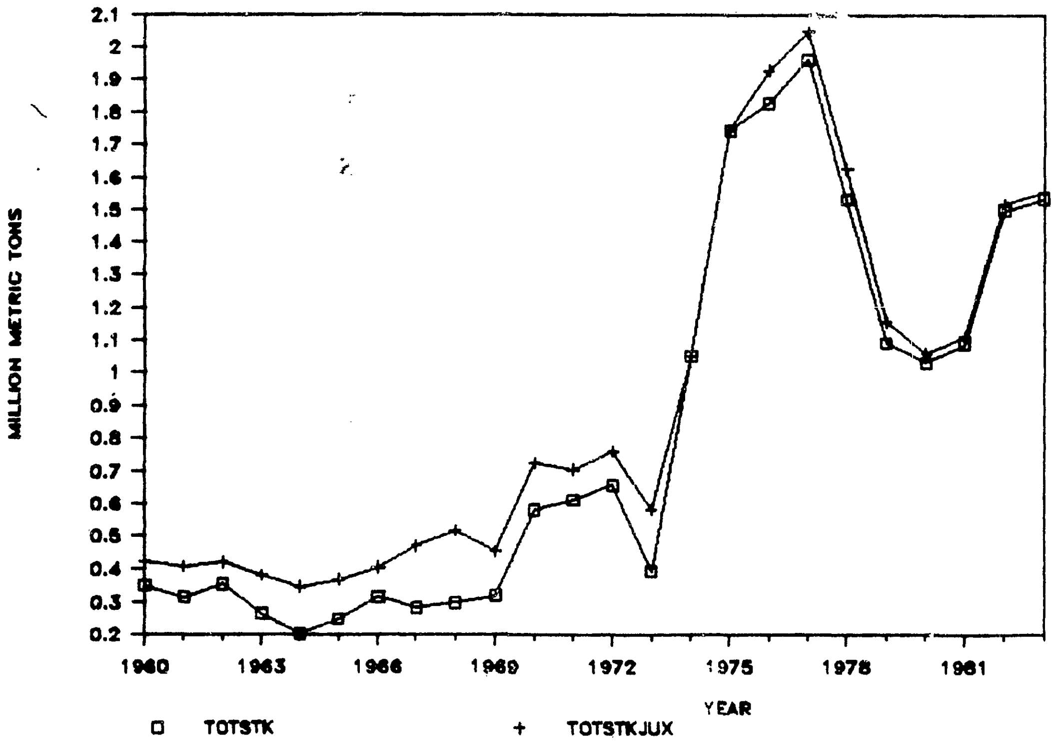
Throughout the period, WMS gives data for consumers' stocks, producers' stocks and merchant stocks for various countries. However, the world total for each of the series are available only for the post-1973 period. To check for consistency in each stockholding category, the world total was obtained by summing up the individual countries' stockholdings for the 1967-1981 period. The calculated total (from individual countries) consumers' stocks, producers' stocks and merchant stocks were then added to the published LME and Comex stocks to yield the calculated total stocks ($TOTSTK^c$) series. $TOTSTK^c$ is consistently higher than TOTSTK for the 1967-1973 period, but identical to TOTSTK for the 1974-1981 period. Given the tendency for under reporting of stockholdings, the observed downward bias in the published stocks data up to 1973 is not surprising. This observation is critical as the simulation results will subsequently show.

Thus it was decided to juxtapose the observed and calculated stocks data series to obtain the total stocks series TOTSTKJUX. In this series, data for 1967-1973 is extracted from $TOTSTK^c$ while data for 1974-1981 is that from the most recent issue of the WMS. To revise the WMS data for total stocks during 1960-1966, $TOTSTK^c$ was first regressed on TOTSTK for the entire 1967-

1981 period. The regression coefficients are then applied to the published stocks data for 1960-1966 to obtain $TOTSTK^c$ for the period. The resultant total stocks series TOTSTKJUX for the 1960-1981 period is presented and graphed in Figure 5.2 for a comparison with the published TOTSTK series. It will be seen that TOTSTKJUX is consistently higher than the published data throughout the 1960-1973 period. This finding is interesting as it seems to imply constant under-reporting of stockholding in the market, thereby adding to the difficulty of assessing market prospects and of forecasting copper price in the short term.

Using the TOTSTKJUX series, the different categories of stockholding by ownership can be estimated. Simple regressions of the different categories of stocks on TOTSTKJUX were conducted for the period 1967-1973, 1967-1981 and 1973-1981. In general, it was found that stockholding behavior differed for the period before and after 1973. Although the different categories of stockholding are not individually used in the modelling exercise, the results provide some interesting insights into the market. The year 1973 marks a watershed in the copper market because it was the year when the world copper market experienced a marked shortage of, and hence, a scramble for copper. This was manifest in the price differential of US$450 per metric ton between the Comex and the US domestic producers' price, and influenced investments favoring copper mine capacity expansions. The oil price quadrupling in late 1973 and subsequent recession led to an era of lower copper demand growth. This in turn affected supply through the slowing down of the rate of completion of new copper mines and lower investment in mine development. A theoretical analysis of this is given empirical substantiation for the case of copper by Radetzki and van Duyne (1983).

FIGURE 5.2: TIME PATHS OF PUBLISHED VERSUS COMPUTED TOTAL STOCKS, 1960-1983 (MILLION METRIC TONS).



YEAR	TOTSTK	TOTSTKJUX
1960	0.349	0.421
1961	0.314	0.408
1962	0.356	0.422
1963	0.264	0.383
1964	0.203	0.347
1965	0.248	0.370
1966	0.315	0.405
1967	0.283	0.473
1968	0.298	0.517
1969	0.319	0.454
1970	0.582	0.724
1971	0.612	0.705
1972	0.659	0.762
1973	0.394	0.585
1974	1.049	1.049
1975	1.744	1.744
1976	1.828	1.928
1977	1.964	2.047
1978	1.535	1.627
1979	1.090	1.153
1980	1.029	1.057
1981	1.087	1.112
1982	1.499	1.519
1983	1.535	1.555

The juxtaposed total stocks data series (TOTSTKJUX) was used in estimating the equation for LME price formation.

5.4.3 Total Stocks Equation

To close the model, the balance identity for total stocks

$$TOTSTK = TOTSTK_{-1} + QRWW + DG + NX - CRWW$$

is required. For an idea of how well the total stocks series generated by this identity compares with the computed stocks series TOTSTKJUX, the total stocks series built up from an initial level of total stocks and current values of all other right-hand side variables was derived. Since there are discrepancies between the two stocks series, it was decided to estimate the balance equation identity using TOTSTKJUX and with the constant suppressed. In the model simulations the balance identity with unit coefficients is used alternatively with the estimated identity (with coefficients not necessarily equal to one) for a comparison of their performance.

VI. MODEL STRUCTURE AND EMPIRICAL VALIDATION

6.1 The Model Structure

As set out above, the world copper market has been represented as a set of submodels of copper demand, supply, US net trade in copper, and primary and secondary refined copper price formation. Before presenting the empirical validation results, the equations of the model are first summarised for ease of reference. Each endogenous variable is presented as a function of its explanatory variables. Equations are presented in the order of demand, supply, US net trade and prices.

The model for the copper market consists of the following equations:

1. $CRBRA = f_1\,[IPIBRA,\ PLMEBRA,\ TIME]$
2. $CRCAN = f_2\,[IPICAN,\ CRCAN_{-1},\ AVPUSCAN_{-1},\ TIME,\ PALUSCAN_{-2}]$
3. $CRCHI = f_3\,[IPICHI,\ \tfrac{1}{2}\sum_{i=1}^{2} PLMEUS_{-i}\ CRCHI_{-1}]$
4. $CRFRA = f_4\,[IPIFRA,\ PLMEFRA_{-2},\ PALWGFR_{-2}]$
5. $CRITA = f_5\,[IPIITA,\ \tfrac{1}{2}\sum_{i=1}^{2} (PLMEUK/PALLME)_{-i}\ TIME]$
6. $CRIDA = f_6\,[IPIIDA,\ (PLME^{uk}/PALLME)_{-1},\ DV7477]$
7. $CRJAP = f_7\,[IPIJAP,\ PCUALJAP_{-2}\quad]$
8. $CRSK = f_8\,[IPIISK,\ PLMESK]$
9. $CRUK = f_{10}\,[IPIUK,\ \tfrac{1}{2}\sum_{i=1}^{2} (PLME/PALLME)_{-i},\ TIME]$
10. $CRUSA = f_{11}\,[IPIUSA,\ \tfrac{1}{2}\sum_{i=1}^{2} (PUS/PALUSA)_{-i},\ TIME]$
11. $CRWG = f_{12}\,[IPIWG,\ \tfrac{1}{2}\sum_{i=1}^{2} (PLME/PALWG)_{-i},\ TIME]$
12. $CRROWW = f_{13}\,[CRROWW_{-i},\ PLMEMUV_{-2},\ TIME]$
13. $QAUS = f_{14}\,[MCAPAUS,\ PLMEAUS]$
14. $QCAN = f_{15}\,[MCAPCAN,\ PUSCAN]$
15. $QCHL = f_{16}\,[MCAPCHL]$
16. $QMEX = f_{17}\,[MCAPMEX,\ PLMEMEXMUV_{-3}]$
17. $QPER = f_{18}\,[MCAPPER,\ PLMEPER]$

18. QPHI = f_{19} [MCAPPHI, $\frac{1}{2} \sum_{i=1}^{2}$ $PLMEPHI_{-i}$]

19. QPNG = f_{20} [MCAPPNG, TIME]

20. QRSA = f_{22} [MCAPRSA, $PLMERSA_{-1}$]

21. QZAI = f_{22} [MCAPZAI, PLMEZAI, DV7880]

22. QZAM = f_{23} [MCAPZAM, PLMEZAM]

23. QUSA = f_{24} [MCAPUSA, NMUSA, PUS/CPIUS, DV6768]

24. QROWW = f_{25} [MCAPROWW, (PLMEUS/MUV)]

25. SCRUSA = f_{26} [$SCRUSA_{-1}$, PSC2USA, $PSC2USA_{-1}$]

26. SCRWWOR = f_{27} [PSC2USA/MUV, TIME]

27. QREFUSA1 = f_{28} [QUSA, NMOCUSA, $\frac{1}{2} \sum_{i=1}^{2}$ $PSTKUSA_{-i}$]

28. QREFROWW1 = f_{29} [QWWORNUSA, $PLME1US_{-1}$, $QREFROWW1_{-1}$]

29. NMOCUSA = f_{30} [(PUS-PLMEUS)/CPIUS, TIME, DV1980]

30. NMRUSA = f_{31} [(CRUSA-QREFUSA), (PUS-PLMEUS)/CPIUS, POIL/CPIUS]

31. NXCOMECON = f_{32} [PLME1UK, $NXCOMECON_{-1}$]

32. PSTKUSA = f_{33} [CRUSA, $PSTKUSA_{-1}$, $DPSTKUSA_{-3}$]

33. TOTSTKJUX = f_{34} [$TOTSTKJUX_{-1}$, QREFWWOR, NXCOMECON, ΔGSTK, CRWWOR]

34. PLME1UK = f_{35} [$TOTSTKJUX_{-1}$, [CRWW/QRWW+NX+DG, RR1UK+DEFOECD]

35. PUS_1 = f_{36} [PLME1US, PUS_{-1}]

36. PSC2USA = f_{37} [PUS_1, DV1969, DV7374]

Identities

37. CRWWOR = CRBRA + CRCAN + CRCHI + CRFRA + CRIDA + CRITA + CRJAP + CRSK + CRUK + CRUSA + CRWG + CRROWW

38. QWWOR = QAUS + QCAN + QCHL + QMEX + QPER + QPHI + QPNG + QRSA + QZAI + QZAM + QUSA + QROWW

39. QREFWWOR = QREFUSA1 + QREFROWW1 + SCRUSA + SCRROWW

40. QREFUSA = QREFUSA1 + SCRUSA

41. NMUSA = NMOCUSA + NMRUSA

List of Endogenous Variables

CRBRA - Consumption of refined copper, Brazil.

CRCAN - Consumption of refined copper, Canada.

CRCHI - Consumption of refined copper, China.

CRFRA - Consumption of refined copper, France.

CRIDA - Consumption of refined copper, India.

CRITA - Consumption of refined copper, Italy.

CRJAP - Consumption of refined copper, Japan.

CRSK - Consumption of refined copper, Republic of Korea.

CRUK - Consumption of refined copper, United Kingdom.

CRUSA - Consumption of refined copper, United States.

CRWG - Consumption of refined copper, Federal Republic of Germany.

CRROWW - Consumption of refined copper, Rest-of-the-Western-World (market economies).

CRWWOR - Consumption of refined copper, total western world (market economies).

QAUS - Mine production of copper, Australia.

QCAN - Mine production of copper, Canada.

QCHL - Mine production of copper, Chile.

QMEX - Mine production of copper, Mexico.

QPER - Mine production of copper, Peru.

QPHI - Mine production of copper, Philippines.

QPNG - Mine production of copper, Papua New Guinea.

QRSA - Mine production of copper, Republic of South Africa.

QZAI - Mine production of copper, Zaire.

QZAM	-	Mine production of copper, Zambia.
QUSA	-	Mine production of copper, United States.
QROWW	-	Mine production of copper, Rest-of-Western-World.
QWWOR	-	Mine production of copper, total western world.
SCRUSA	-	Secondary Supply copper, United States.
SCRWWOR	-	Secondary copper supply, western world, excluding United States.
QREFUSA1	-	Primary refined copper production, United States.
QREFROWW1	-	Primary refined copper production, western world excluding United States.
QREFUSA	-	Primary and secondary refined copper production, United States.
QREFWWOR	-	Primary and secondary refined copper production, total western world.
NMOCUSA	-	Net imports of ores, concentrates and blisters, United States.
NMRUSA	-	Net imports of refined copper, United States.
NMUSA	-	Net imports of ores and concentrates, blisters and refined copper, United States.
NXCOMECON	-	Net refined copper exports of Comecon to the market economies.
PSTKUSA	-	Producer stocks of refined copper, United States.
DPSTKUSA	-	First difference of US producer stocks.

PLME1UK - LME price of refined copper, pounds per metric ton.

PLME1US - LME price of refined copper, US dollars per metric ton.

PUS1 - Domestic producers' price for refined copper, United States.

PUSCAN - US producers' price for refined copper, in Canadian dollars and deflated by CPI of Canada.

AVPUSCAN - Two-year moving average of US producers' price in Canadian dollars, deflated by the CPI of Canada.

PLME/PALLME - Ratio of the LME copper price to the LME aluminum price.

PCUALJAP - Ratio of 1-period lagged LME copper price to 2-period aluminum price lagged, in Japanese yen and deflated by the CPI for Japan.

PLMEAUS - LME price in Australian dollars, deflated by CPI for Australia.

PLMEFRA - LME price in French francs, deflated by CPI for France.

PLMEMEXMUV - LME copper price in Mexican pesos and deflated by the World Bank's MUV.

PLMEPER - LME copper price in Peruvian sols, deflated by the CPI for Peru.

PLMEPHI - LME copper price in Philippine pesos, deflated by the CPI for the Philippines.

PLMESK - LME copper price in Korean won, deflated by the CPI for the Republic of Korea.

PLMEZAI - LME copper price in Zairean zaires, deflated by the CPI for Zaire.

PLMEZAM - LME copper price in Zambian kwachas, deflated by the CPI for Zambia.

PALLME	-	LME price for aluminum, in pounds sterling.
PALLMEBRA	-	LME price for aluminum in Brazilian cruzeiros, deflated by the CPI of Brazil.
PALUSCAN	-	US producers' price for aluminum in Canadian dollars, deflated by the CPI of Canada.
PALWG	-	Aluminum price quoted in the Federal Republic of Germany.
PALWGFR	-	Aluminum price quoted in the Federal Republic of Germany, converted into French francs and deflated by the CPI for France.
POIL	-	Price of crude oil, ex-Ras Tanura.

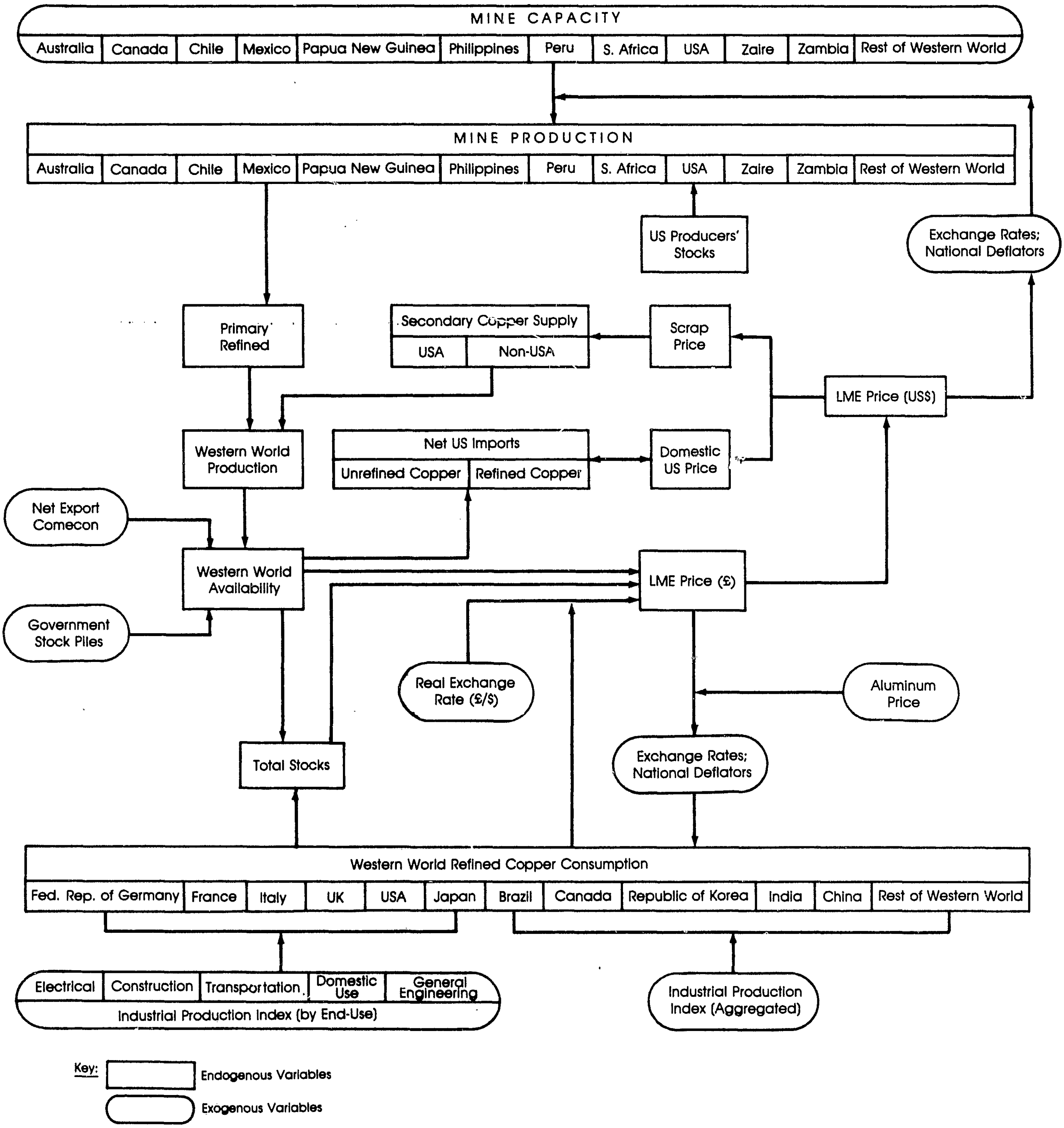
List of Exogenous Variables

IPIBRA	-	Industrial Production Index, Brazil.
IPICAN	-	Industrial Production Index, Canada.
IPICHI	-	Industrial Production Index, China.
IPIFRA	-	Industrial Production Index, France.
IPIITA	-	Industrial Production Index, Italy.
IPIJAP	-	Industrial Production Index, Japan.
IPISK	-	Industrial Production Index, Republic of Korea.
IPIUK	-	Industrial Production Index, United Kingdom.
IPIUSA	-	Industrial Production Index, United States.
IPIWG	-	Industrial Production Index, Federal Republic of Germany.

MCAPAUS	-	Mine Capacity, Australia.
MCAPCAN	-	Mine Capacity, Canada.
MCAPCHL	-	Mine Capacity, Chile.
MCAPMEX	-	Mine Capacity, Mexico.
MCAPPER	-	Mine Capacity, Peru.
MCAPPHI	-	Mine Capacity, Philippines.
MCAPPNG	-	Mine Capacity, Papua New Guinea.
MCAPRSA	-	Mine Capacity, Republic of South Africa.
MCAPZAI	-	Mine Capacity, Zaire.
MCAPZAM	-	Mine Capacity, Zambia.
MCAPUSA	-	Mine Capacity, United States.
MCAPROWW	-	Mine Capacity, Rest-of-Western-World.
DV6768	-	Dummy variable for severe strikes in US copper mining industry.
DV1969	-	Dummy variable for escalation of the Vietnam War.
DV7374	-	Dummy variable for the first oil crisis.
DV7477	-	Dummy variable for the 1974-1977 period during which copper prices in India were regulated.
DV7880	-	Dummy variable for political troubles in the Shaba province of Zaire.
EXRUK	-	Exchange rate for pound sterling per US dollar.
DEFOECD	-	GDP Deflator for OECD countries.
MUV	-	World Bank's MUV-deflator.
RR1UK	-	Real effective rate of exchange between the pound sterling and the US dollar.

Figure 6.1 illustrates the structure of the model which will now be briefly described and summarized. The model is disaggregated by major

FIGURE 6.1: STRUCTURE OF THE WORLD COPPER MARKET MODEL



consuming and producing countries to permit analysis of behavioral patterns, mainly in response to prices. It also attempts to reflect the changing relationship between the United States and other producing countries by distinguishing the US producers' price from the LME price and by analyzing US mine production in conjunction with US copper trade.

The model focuses on western world demand for refined copper only, separating out the major consumers. A rest-of-the-western-world consumption equation captures the balance of consumption in the world (excluding the Comecon countries). For each separately-identified country, refined copper consumption is estimated as a function of the industrial production index, the copper price, the price of aluminum (which is a major substitute), and a trend variable to capture the decline in copper consumption because of material substitution away from copper due to technological reasons.

Because of the recent rapid changes in the structure of the copper market, it was felt that copper investment functions estimated from historical data would not be relevant to the forecast period; therefore, to allow for maximum flexibility in exploring alternative investment behavior in the producing countries, it was decided to treat mine capacities for all countries exogenously. Mine production or supply is estimated as a function of mine capacity and the copper price. Separate supply equations are estimated for the major producers.

Since the reference price used in the international market is for refined copper, mine production must be translated into refined copper supply for use in the refined copper price formation function. This raises the question of the extent to which producing countries are involved in the refined copper trade. The United States stands apart from the other producing countries in that it is a major producing as well as consuming country and refines the bulk of its mine output domestically. Consequently, the conversion of US mine output into primary refined copper is treated independently. The non-US mine production is aggregated before conversion to non-US primary refined copper output. Similarly, secondary scrap recovery is differentiated into US and non-US scrap production. The total western world's refined copper supply is then the sum of primary refined and scrap supply. Since the LME price is influenced by the western world's availability of refined copper, total supply in each period is adjusted for changes in the government's stockpiles of refined copper and for the net refined copper imports from the Comecon countries.

In any period, the difference between refined production and consumption leads to a change in the total stocks level, which is an explanatory variable in the LME price formation process. Other determinants of the LME price are the ratio of consumption to world (excluding Comecon) copper availability, the inflation rate in the OECD countries and the real exchange rate between the pound sterling and the US dollar.

Once the LME price is determined, the domestic US producers' price and the scrap price are determined via the price linkage equations. The linkage of scrap price to the LME price is direct, while that between the US producers' price and LME price is less direct. This is because in the 1964-83 period under study, the US copper industry gradually lost ground as the leading producer. The changing relationship between the United States and the other major producers is reflected in the changing composition of net US copper imports and is also manifested in the 1978 shift from independent determination of the US producers' price to determination on the basis of a premium over the New York Commodity Exchange's (Comex) quotation.

The estimation period for the model is 1964-1983. While this sample period is shorter than desirable for sound econometric analysis, it was used nevertheless for the following reasons. The majority of major developing producing countries nationalized their copper industries in the mid-1960s, leading to substantial restructuring of the industry. Further, up to the 1960s the aluminum industry was rapidly penetrating copper markets through lower prices and aggressive R & D and marketing activities. Therefore, analysis of copper demand by end-uses is necessary for an understanding of the differential rates of substitution between copper and aluminum in different industries, as well as for exploring potential substitution by new products such as fiber optics in the future period. Such end-use copper consumption data are available only from 1968.

The model has been structured so that a diversity of scenarios may be analyzed. For example, on the question of US producer's price, the model allows price projections under alternative scenarios regarding US productivity growth or mine openings or closures. Under the scenario wherein the US copper industry undertakes modernization to increase productivity, a return to the two-price system where the US producers' price differs significantly from the world price may be envisaged in a protectionist environment. Alternatively, should the US copper industry choose to move in the direction of further integration with the world market, a convergence of the US producers' price and LME price may be envisaged.

6.2 Empirical Validation of the Model

In validating the model over the 1970-1983 period, static and dynamic solutions were reached with less than 20 iterations under the convergence criterion of 0.001%. Overall, the model tracked the production and consumption variables reasonably well. Under dynamic simulation, mine production for the following countries had less than 7% root mean squared percentage error: Australia, Chile, Papua New Guinea, Peru, the Philippines, South Africa, Zaire, Zambia and the rest-of-the-Western-world (ROWW). Producing countries with 7-12% root mean squared percentage errors for mine production were Canada, Mexico and the United States. The higher simulation errors may be attributed to the inadequacy of the estimated mine production equations in capturing various changes in these countries during the historical period, such as the sudden mine capacity expansion in Mexico in 1979-1980, the change in US producers' pricing in 1978 which is not fully accounted for in the estimated equation for US producers' price, and the role of high nickel prices in Canadian copper production.

The dynamic tracking of consumption was subject to greater error. While predicted consumption for China, Italy, the Federal Republic of Germany, the United Kingdom, the United States and the ROWW had root mean squared percentage errors of under 7%, errors exceeding 7% were found for Brazil, Canada, France, India, Japan, and the Republic of Korea. The poorer performance of these consumption equations may be attributed to the fact that substitutes other than aluminum--such as plastics and stainless steel--are not accounted for explicitly. Furthermore, since consumption refers only to refined copper consumption and not to semi-fabricates (such as copper wires), the refined copper consumption data do not always reflect total copper consumption.

Under dynamic simulation, total Western world refined copper consumption and production, and mine production had root mean squared percentage errors of less than 5%. Less satisfactory root mean squared percentage errors of 15-25% were obtained for the total stocks, the LME price, the US producers' price and scrap price variables. The poorer performance of the stocks and price variables are inter-related since the total stocks variable is an explanatory variable for the LME price, which in turn explains the US producers' price and the scrap price. Another reason for the poorer tracking record of the variables is the change in US producers' pricing in 1978. Strictly speaking, the equation specified according to pricing behavior in the pre-1978 period is inappropriate for simulating the post-1978 period and vice versa. However, since the pre-1978 period dominates the 1964-83 estimation period, it was decided to estimate the equation over the entire period and use it for one set of simulations.

6.2.1 Alternative Specifications of US Producers' Pricing Behavior

Table 6.1 presents simulation errors for total mine production, refined copper production, consumption, stocks, and the three price variables to demonstrate the sensitivity of the model to various combinations of the US producers' price and total stocks equations. Simulation errors are lowest for Case A which uses the US producers' price equation based on price behavior before 1978 and the estimated total stocks equation. In the other 3 cases, simulation errors for the price and stocks variables tend to be larger. These results for cases A', B and B' were to be expected since the Comex-based US producers' pricing was in effect in only 5 of the 20 years of the estimation

TABLE 6.1: COMPARISON OF SIMULATION ERRORS UNDER ALTERNATIVE COMBINATIONS OF US PRODUCERS' PRICE AND TOTAL STOCKS EQUATIONS, 1971-1983

Variable	CASE A MAPE	CASE A RMSPE	CASE A' MAPE	CASE A' RMSPE	CASE B MAPE	CASE B RMSPE	CASE B' MAPE	CASE B' RMSPE
CRWWOR	3.5	4.0	3.6	4.3	3.6	4.3	3.6	4.4
QWWOR	2.3	3.1	2.4	2.9	1.7	2.6	2.5	2.7
QREFWWQR	3.1	3.6	3.3	3.8	2.9	3.3	3.8	4.1
TOTSTKJUX	19.7	24.1	30.3	35.3	22.3	24.6	25.2	32.8
PLME1US	16.8	23.2	19.4	25.9	17.6	22.4	16.2	21.1
PUS1	19.0	22.0	17.1	20.5	19.5	25.8	17.9	23.9
PSC2USA	17.9	20.4	15.7	18.0	16.7	21.1	14.8	19.2

Notes: Case A for estimated US producers' price equation and total stocks equations; Case A' for estimated US producers' price equation and total stocks identity; Case B for Comex-based US producers' price equation and total stocks equation; Case B' for Comex-based US producers' price equation and total stocks identity.

TABLE 6.2: SIMULATION ERRORS FOR PRICES UNDER ALTERNATIVE US PRODUCERS' PRICE DETERMINATION PROCESSES, 1971-1977 AND 1978-1983

		1971-77 MAPE	1971-77 RMSPE	1978-83 MAPE	1978-83 RMSPE
Case A					
	PLME1US	17.8	24.0	15.0	17.8
	PUS1	15.6	17.7	19.5	25.2
Case B					
	PLME1US	16.5	21.2	15.2	17.6
	PUS1	21.6	28.2	13.2	15.9

Notes: Case A for US producers' price equation as in two-price system behavior; Case B for US producers' price based on Comex price. MAPE and RMSPE refer to mean absolute percentage error and root mean squared percentage error, respectively.

period. Results for the four cases also show smaller simulation errors when the estimated total stocks equation is used instead of the total stocks balance identity.

Using the total stocks identity (coefficients of 1.0), the model was alternatively simulated with the different US producers' price equations for the 1971-1977 and 1978-1983 periods. Table 6.2 presents the prediction errors for the four simulations, and shows that prediction errors for the US producer's price (PUS1) are smaller in the model version using the 2-price system behavior for 1971-1977, than in the version using Comex-based producers' price for 1978-1983. These results substantiate the argument that in the two-price system before 1978, the US producers' price was determined by both the LME price and its own lagged values. Use of the Comex-linked (and hence LME-linked) US producers' price equation for the 1971-1977 period gives significantly higher simulation errors. Conversely, the relevance of the Comex-based US producers' pricing in the 1978-1983 period is reflected in the significantly lower simulation errors for the US producers' price variable. Table 6.2 also shows that the simulation errors vary considerably for the US producers' price, depending on the choice of US producers' price equation in the pre- and post-1978 periods. These simulation errors substantiate the view that whatever the manner of US producers' pricing, it is the LME price that ultimately influences the market.

Figure 6.2 presents the actual and dynamically-simulated timepaths of key variables in the 1970-1983 period for the Case A combination of equations. Bearing in mind the level of simulation errors obtained, the combination of US producers' price and total stocks equation as in Cases A and B have been used for model simulations to explore the impact of alternative assumptions about aluminum prices and exchange rates.

FIGURE 6.2: ACTUAL AND DYNAMICALLY-SIMULATED TIME PATHS OF KEY VARIABLES, 1971-1983

(+ actual ▫ simulated)

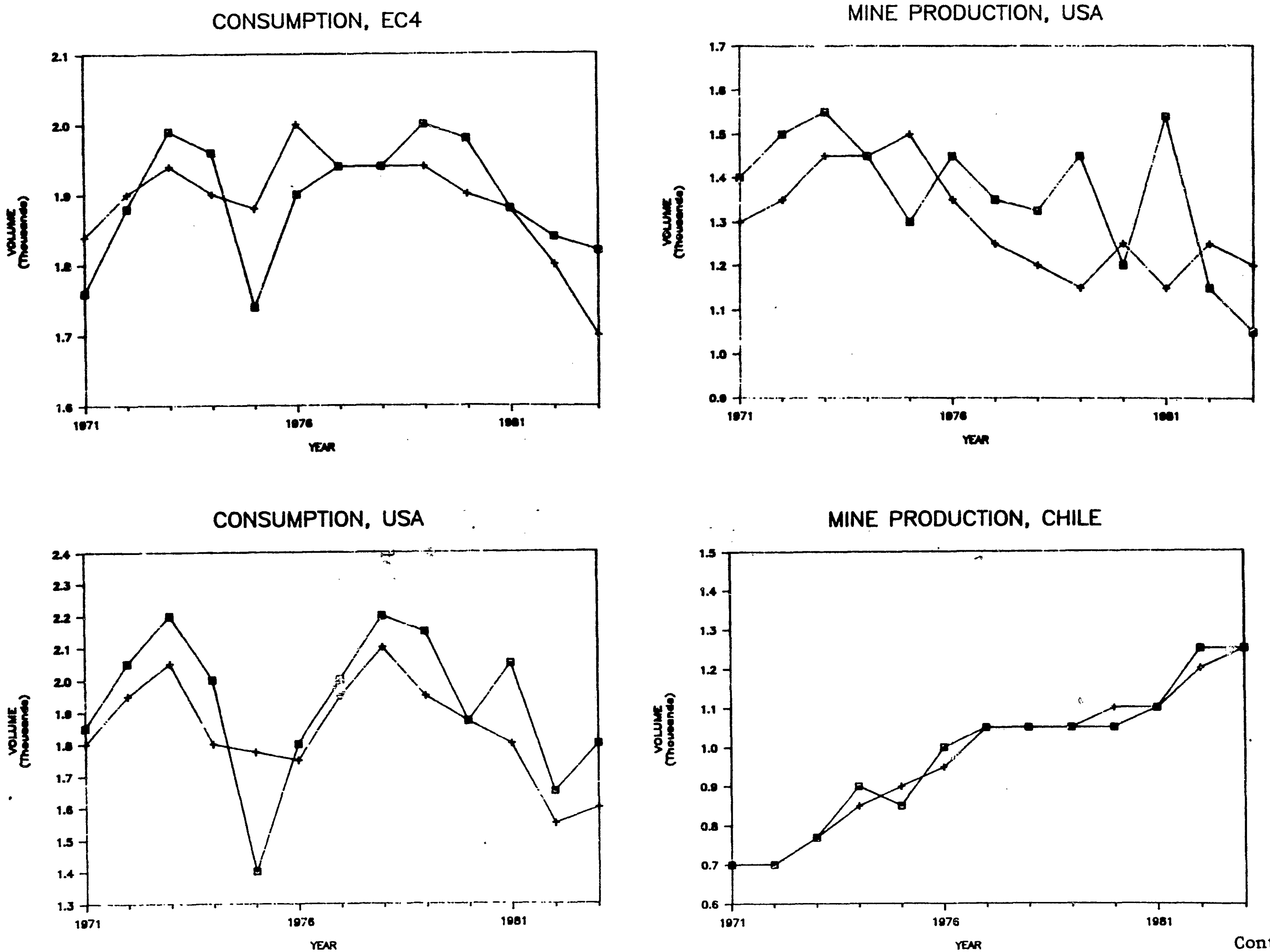


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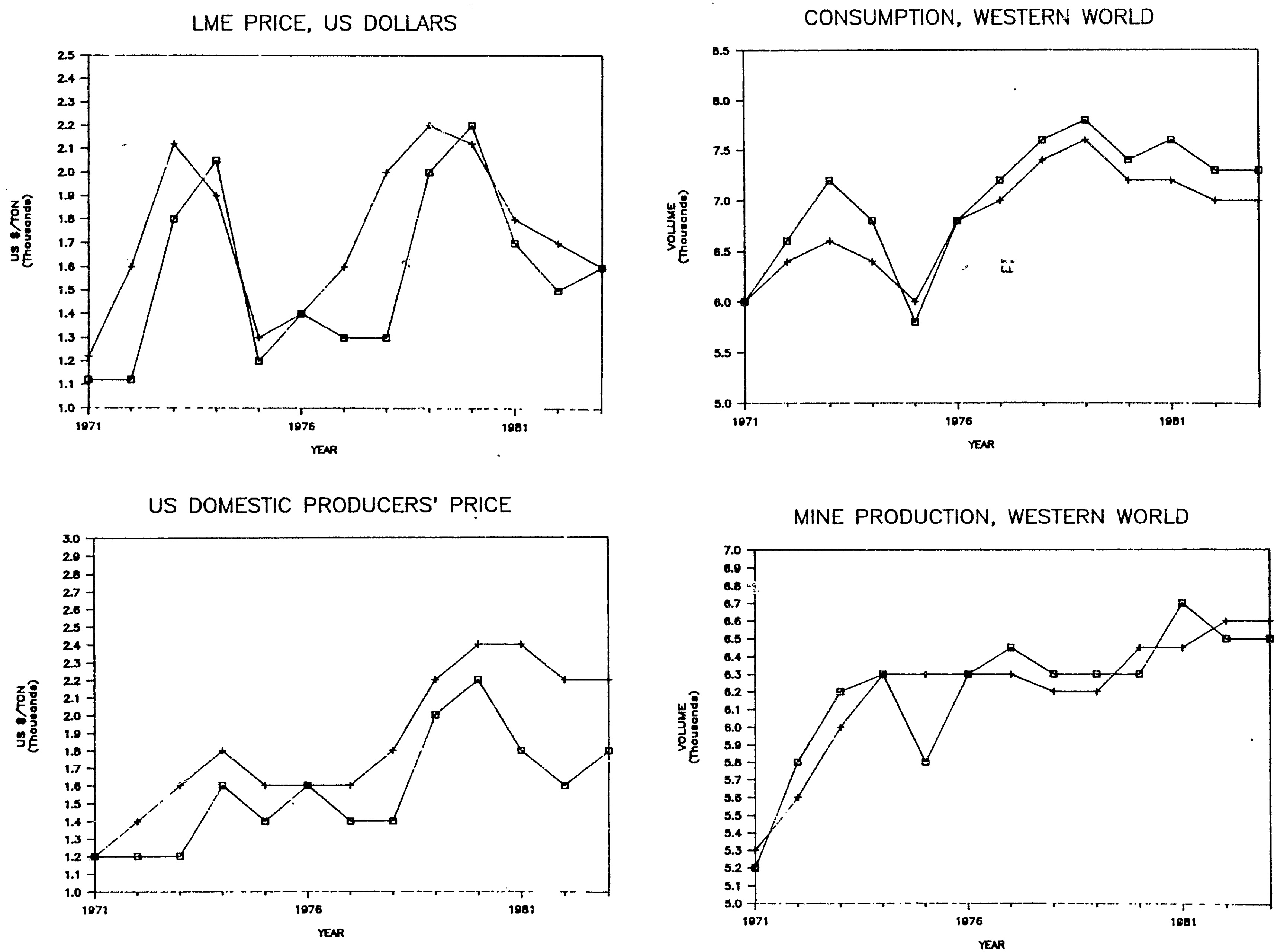
FIGURE 6.2: continued



6.2.2 Higher Aluminum Prices

Up to the mid-1970s, copper prices were consistently higher than aluminum prices, with the relative price ratio ranging from 1.5 to 3.2. In recent years the ratio has been tending towards unity. Those familiar with the copper industry have suggested that at 65% of the price of aluminum, copper could begin to take market share from aluminum. To examine the implications of such a reversal in the historical price ratio, the model was simulated with the copper-to-aluminum price ratio fixed at 0.65 throughout the 1971-1983 period. This is executed in the model by endogenising the aluminum price variable; the aluminum price is thus obtained as the solution value from the copper-to-aluminum price ratio which is forced to be 0.65 throughout. Table 6.3 presents the results. Case A uses the estimated US producers' price; Case B uses the LME-linked US producers' price.

The simulation results of cases A and B are qualitatively similar. The impact of the relatively higher aluminum price on copper consumption is uneven across countries. For the four major EC countries (EC-4), the total consumption of copper rises by about 7%. For the United States and Japan, the relatively higher aluminum prices lead to reduced copper consumption, with a sharper reduction in the United States. Total Western World consumption is unaffected in volume but is nearly 17% higher in value. While the increase in the EC-4 consumption is as expected, the fall in US consumption may seem surprising. But if the US producer's price is considered, the effect of reduced copper consumption in the face of a relatively higher aluminum price is not so surprising. This is because the higher aluminum prices allow a higher LME price for copper, and hence, a higher US producers' price. Under case A where the unified producers' pricing is applied throughout the period, the relatively higher aluminum price would induce a 27% increase in the US

TABLE 6.3: EFFECTS OF HIGHER ALUMINUM PRICES THROUGHOUT 1971-1983

Variables		Actual	Case A		Case B	
PLME1US (average)	- US$/ton	1535.50	1809.70	(+17.9)	1811.40	(+18.5)
PUS1 (average)	- US$/ton	1582.20	2012.90	(+27.2)	1938.20	(+22.5)
Mine Production						
Chile	- million tons	12.70	12.72	(+0.2)	12.72	(+0.2)
	- million US$	19.77	23.09	(+16.8)	23.31	(+17.9)
Peru	- million tons	3.70	3.79	(+2.4)	3.78	(+2.2)
	- million US$	5.2	6.96	(19.6)	7.02	(+20.0)
Zaire	- million tons	6.05	6.03	(-0.3)	6.02	(-0.5)
	- million US$	9.32	10.86	(+16.5)	10.85	(+16.4)
Zambia	- million tons	8.34	8.41	(+0.8)	8.41	(+0.8)
	- million US$	12.72	15.17	(+19.3)	15.12	(18.8)
USA	- million tons	17.70	17.59	(-0.6)	17.46	(-1.4)
	- million US$	27.78	35.07	(26.2)	33.61	(+21.0)
Western World	- million tons	80.64	81.41	(+1.0)	81.21	(+0.7)
	- million US$	124.73	147.53	(+18.3)	147.62	(18.3)
Refined Copper Production						
USA	- million tons	23.62	24.04	(+1.8)	23.82	(+0.8)
	- million US$	37.26	48.30	(+29.5)	46.11	(+23.8)
Western World	- million tons	91.90	91.22	(-0.7)	90.81	(-1.2)
	- million US$	142.39	165.59	(+16.3)	165.32	(+16.1)
Refined Copper Consumption						
USA	- million tons	24.96	23.52	(-5.8)	23.57	(-5.6)
	- million US$	39.53	47.30	(+19.6)	46.07	(+16.5)
EC-4	- million tons	24.60	26.41	(+7.4)	26.44	(+7.5)
	- million US$	38.01	47.79	(+25.8)	47.75	(+25.6)
Japan	- million tons	14.29	14.12	(-1.2)	14.12	(-1.2)
	- million US$	22.28	25.49	(+14.4)	25.65	(+15.1)
Western World	- million tons	90.79	90.38	(-0.5)	90.45	(-0.4)
	- million US$	141.05	164.41	(+16.6)	164.78	(+16.8)

Notes: Case A uses historical US producers' price equations;
Case B uses LME-linked US producers' price equation.
Figures within parentheses denote percentage changes of the simulated from the actual values of each variable.

producers' price. Despite the resultant fall in US copper consumption, US copper consumption expenditure increases by 20%. Had the US market been fully integrated with the world market, then the impact of higher copper price on US consumers would be similar to that for the EC-4 consumers; that is the copper market would have benefitted through increased consumption which would result in higher prices. This would translate into higher producers' earnings and royalties.

The simulations show that had aluminum prices been consistently higher than copper prices, increased copper consumption would set in motion upward pressure on copper prices and royalties. Given the relatively inelastic demand, the copper price would be 18% higher than the observed average and would increase copper revenues of producing countries by some 18-20%. For the US producers, the effect of the higher aluminum price depends on the extent to which the domestic producers' price is influenced by the LME price. Under case A where US producers' pricing is assumed, the higher aluminum prices lead to a 27% rise in US domestic producers' price for copper for the same output. Under case B where the US producers' price is systematically linked to the LME price, the net effect of higher aluminum and hence higher copper prices is a 1.5% reduction in US production alongside the 5.6% fall in consumption. Comparing cases A and B, the higher US copper consumption with lower domestic production in case B is facilitated through increased imports from the rest of the western world. In summary, the secular decline in copper price may be attributed in part to the low aluminum price in the historical period.

The simulation values for key variables in selected years are presented in Tables 6.4 (case A) and 6.5 (case B).

TABLE 6.4: CASE A - SIMULATION RESULTS OF HIGHER ALUMINUM PRICES, 1971-1983

COUNTRY/REGION	1972	1975	1980	1981	1982	1983
CONSUMPTION						
WESTERN WORLD	6729.3	6209.2	7313.5	7364.2	7061.0	6857.7
USA	1937.1	1399.3	1899.9	1891.2	1538.0	1532.4
FRANCE	470.5	437.3	402.5	408.1	389.9	350.4
ITALY	343.2	330.2	400.5	389.0	366.3	352.3
UK	617.9	594.4	458.5	402.3	380.0	374.8
GERMANY, F.R.	722.6	688.5	736.9	742.9	711.8	680.8
JAPAN	1030.3	981.1	1069.1	1213.1	1300.7	1146.6
BRAZIL	100.1	162.4	231.2	171.3	202.9	173.5
CHINA	241.8	267.7	335.7	346.8	365.5	381.6
KOREA, REP.	2.3	38.1	97.9	115.4	122.3	144.0
MINE PRODUCTION						
WESTERN WORLD	5722.3	6412.5	6444.5	6419.3	6610.8	6620.1
USA	1459.5	1602.1	1268.4	1145.7	1272.3	1233.3
CHILE	714.4	891.0	1094.5	1123.5	1178.8	1247.4
PERU	218.1	180.8	369.7	356.8	355.5	353.5
ZAIRE	441.4	530.0	401.3	448.1	460.4	474.1
ZAMBIA	723.6	691.4	587.6	578.9	562.5	531.6
REFINED COPPER OUTPUT						
WESTERN WORLD	6358.6	7059.4	7298.5	7375.7	7517.6	7498.9
USA	1931.4	2003.1	1806.4	1742.2	1806.9	1719.1
PRICES (US DOLLARS)						
USA	1565.5	1858.9	2467.4	2523.6	2440.3	2259.9
LME	1854.4	1341.4	2146.6	1973.2	1792.3	1619.4
TOTAL STOCKS	108.8	1640.6	797.3	851.9	1226.1	1696.6

TABLE 6.5: CASE B - SIMULATION RESULTS OF HIGHER ALUMINUM PRICES, 1971-1983

COUNTRY/REGION	1972	1975	1980	1981	1982	1983
CONSUMPTION						
WESTERN WORLD	6732.3	6240.7	7268.4	7374.5	7102.0	6897.0
USA	1903.0	1388.3	1857.8	1902.2	1600.2	1615.7
FRANCE	470.5	437.3	402.5	408.1	389.9	350.4
ITALY	346.1	331.4	401.2	388.8	364.1	348.5
UK	625.9	599.4	459.8	402.2	376.6	368.5
GERMANY, F.R.	727.0	704.1	735.2	745.5	710.7	673.0
JAPAN	1045.3	1008.7	1073.7	1219.5	1290.1	1120.0
BRAZIL	101.3	162.1	231.7	170.7	201.0	171.0
CHINA	244.7	273.1	335.0	346.3	362.6	375.0
KOREA, REP.	4.3	37.9	98.1	115.1	121.6	143.0
MINE PRODUCTION						
WESTERN WORLD	5857.9	6235.0	6401.0	6323.5	6500.8	6522.7
USA	1582.8	1471.8	1239.9	1070.7	1177.2	1141.0
CHILE	714.4	891.0	1094.5	1123.5	1178.8	1247.4
PERU	211.8	181.3	368.8	357.8	358.3	357.7
ZAIRE	439.3	526.9	401.1	447.9	460.7	475.0
ZAMBIA	719.0	692.1	586.9	580.0	565.4	535.8
REFINED COPPER OUTPUT						
WESTERN WORLD	6517.1	6789.2	7221.4	7215.8	7346.9	7339.6
USA	2047.4	1849.0	1763.3	1645.4	1694.0	1617.0
PRICES (US DOLLARS)						
USA	1823.6	1453.4	2261.9	2162.5	2054.7	1921.8
LME	1704.3	1358.3	2113.9	2021.0	1920.3	1796.1
TOTAL STOCKS	278.2	1556.4	826.4	758.1	991.2	1357.7

6.2.3 Impact of the US Dollar Held at 1984 Exchange Rate throughout 1971-1983

With floating exchange rates being adopted by many, particularly industrial, countries there has been increased interest in the question of the role of exchange rates in the determination of primary commodity prices quoted in US dollars. As the LME price equation shows, exchange rate movements can affect the dollar-value price level, ceteris paribus. The recent appreciation of the US dollar and its differential impacts on different countries has been cited as one of several factors adversely influencing the performance of US copper mines. For example, the exchange rate for the US dollar against the basket of major currencies (excluding the US dollar) appreciated by 11.25% between 1983 and 1984. Consequently, the 1984 inflation rate for industrial countries was -1% in terms of the US dollar GNP deflator, but was +3.3% in terms of national currency GNP deflators. Here the model is used to study the impact of changes in the US dollar exchange rate on the copper industry. In simulating the model the US dollar is assumed to have the high 1984 exchange rate value throughout the 1971-1983 period. The 1984-adjusted exchange rates used for all producing and consuming countries were calculated from the formula:

1984 actual exchange rate * (local CPI/CPI for the US)

Table 6.6 presents the 1984-adjusted exchange rates used in the model simulations. 1/ As for the previous simulations, these adjusted exchange rates

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1/ These adjusted exchange rates were calculated by Shun-Ichi Maeda of the Bank's Industry Department and their use is gratefully acknowledged.

Table 6.6: 1984-ADJUSTED EXCHANGE RATES FOR COPPER PRODUCING COUNTRIES, 1970-1984

	AUSTRALIA	BRAZIL	CANADA	CHILE	FRANCE	GERMANY,FR.	ITALY	JAPAN
1970	0.85	8.32	1.18	0.05	6.08	3.80	784.54	235.60
1971	0.87	9.62	1.16	0.06	6.15	3.83	787.99	239.80
1972	0.89	10.72	1.18	0.10	6.32	3.92	808.01	242.49
1973	0.91	11.41	1.19	0.45	6.39	3.94	843.06	255.00
1974	0.95	13.10	1.19	2.42	6.55	3.80	904.11	285.96
1975	1.00	15.53	1.21	10.53	6.71	3.69	968.86	292.95
1976	1.07	20.82	1.23	31.06	6.96	3.64	1070.30	302.80
1977	1.13	28.00	1.25	55.97	7.14	3.54	1175.30	307.11
1978	1.13	36.13	1.26	72.87	7.24	3.38	1225.30	296.36
1979	1.11	49.60	1.24	87.32	7.20	3.16	1263.10	275.79
1980	1.08	79.89	1.20	104.00	7.21	2.94	1349.20	262.45
1981	1.07	148.80	1.23	112.74	7.41	2.83	1439.60	249.37
1982	1.12	277.69	1.28	116.88	7.81	2.81	1580.70	241.38
1983	1.20	650.89	1.31	144.00	8.29	2.81	1755.40	237.92
1984	1.19	1847.00	1.31	160.92	8.53	2.78	1712.40	234.69
	KOREA, REP.	**MEXICO**	**PERU**	**PHILIPPINES**	**S.AFRICA**	**UK**	**ZAIRE**	**ZAMBIA**
1970	347.40	14.22	51.92	6.08	0.92	0.41	0.63	0.94
1971	378.12	14.35	53.60	6.71	0.93	0.42	0.63	0.96
1972	408.18	14.59	55.59	7.14	0.96	0.44	0.71	0.98
1973	396.48	15.41	57.57	7.67	0.99	0.45	0.78	0.98
1974	444.81	17.17	60.53	9.22	0.99	0.47	0.89	0.95
1975	510.30	18.13	68.42	9.14	1.03	0.54	1.05	0.96
1976	556.08	19.85	85.80	9.18	1.09	0.59	1.79	1.08
1977	575.19	24.03	111.89	9.30	1.14	0.65	2.85	1.21
1978	611.87	26.23	163.40	9.29	1.16	0.65	3.93	1.31
1979	650.14	27.84	245.01	9.93	1.18	0.66	7.37	1.29
1980	737.33	31.00	343.89	10.31	1.18	0.69	9.22	1.27
1981	810.13	35.94	546.52	10.58	1.24	0.70	11.28	1.32
1982	819.19	53.80	846.87	11.06	1.34	0.71	14.58	1.39
1983	820.28	105.24	1732.50	11.88	1.45	0.72	24.84	1.59
1984	810.00	173.73	3707.10	18.00	1.57	0.73	37.10	1.87

were applied in simulations using the US producers' price equation (case C) and the LME-linked US producers' price equation (case D), alternatively. Table 6.7 summarizes the effects of using the 1984-adjusted exchange rates over the entire 1971-83 period while Tables 6.8 and 6.9 present the simulation solution values for individual countries in selected years.

The 1984-adjusted exchange rates translate into higher prices for non-US producers, and lead to higher production in countries other than the United States. In contrast, the 1984-adjusted exchange rate renders US production less competitive, thereby leading to a sharp fall in US mine production. On the consumption side, the 1984-adjusted exchange rates translate into higher copper prices in local currencies, and lead to a slight reduction in the value of Western World consumption. The more elastic demand in Japan causes Japanese consumption to fall by 7-8% in the period, compared with about a 2% consumption fall in the EC-4 countries. Depending on which specification of the US producers' price equation is used, copper consumption volume in the United States increases by 0.1% or decreases by 0.9%. This small effect on US consumption of the 1984-adjusted exchange rates contrasts with the larger impact of 1984-adjusted exchange rates on consumption elsewhere where copper is priced in non-US currencies. Consequently, the US domestic producers' price in US dollars is affected only by changes in the LME price resulting from the impact of the 1984-adjusted exchange rates on non-US production and consumption.

Qualitatively, the effects of using 1984-adjusted exchange rates on production, consumption and prices are the same for all countries under cases C and D, except for US consumption and production. When the US producers'

Table 6.7: EFFECTS OF 1984-ADJUSTED EXCHANGE RATES THROUGHOUT 1971-1983

Variables	Actual	Case C		Case D	
PLME1US (average) - US$/ton	1535.50	1576.40	(+2.7)	1521.40	(-0.9)
PUS1 (average) - US$/ton	1582.20	1582.60	(+0.0)	1627.90	(+2.9)
Mine Production					
Chile - million tons	12.70	12.72	(+0.2)	12.72	(+0.2)
- million US$	19.77	20.30	(+2.7)	19.66	(+0.6)
Peru - million tons	3.70	3.89	(+5.1)	3.86	(+4.2)
- million US$	5.82	6.25	(+7.4)	6.00	(+3.1)
Zaire - million tons	6.05	6.27	(+3.7)	6.25	(+3.4)
- million US$	9.32	9.87	(+5.9)	9.49	(+1.9)
Zambia - million tons	8.34	8.57	(+2.8)	8.55	(+2.8)
- million US$	12.72	13.41	(+5.4)	12.89	(+1.3)
USA - million tons	17.70	15.49	(-12.5)	15.82	(-10.6)
- million US$	27.78	24.27	(-12.7)	25.54	(-8.1)
Western World - million tons	80.64	79.50	(-1.4)	79.77	(-1.1)
- million US$	124.73	125.73	(+0.8)	121.88	(-2.3)
Refined Copper Production					
USA - million tons	23.62	21.86	(-7.5)	22.10	(-6.4)
- million US$	37.26	34.46	(-7.5)	35.91	(-3.6)
Western World - million tons	91.90	88.12	(-4.1)	88.31	(-3.9)
- million US$	142.39	139.62	(-1.9)	135.16	(-5.1)
Refined Copper Consumption					
USA - million tons	24.96	24.99	(+0.1)	24.73	(-0.9)
- million US$	39.53	39.55	(+0.0)	40.50	(+2.5)
EC-4 - million tons	24.60	23.98	(-2.5)	24.12	(-1.9)
- million US$	38.01	37.73	(-0.7)	36.60	(-3.7)
Japan - million tons	14.29	13.14	(-8.0)	13.29	(-7.0)
- million US$	22.28	20.77	(-6.8)	20.32	(-8.8)
Western World - million tons	90.79	88.62	(-2.4)	88.66	(-2.3)
- million US$	141.05	140.51	(-0.4)	135.74	(-3.8)

Notes: Case C is with estimated US producers' price equation;
Case D is with Comex-based US producers' price equation.
Figures within parentheses denote percentage changes of the simulated from the actual values of each variable.

TABLE 6.8: CASE C - SIMULATION RESULTS WITH THE 1984-ADJUSTED EXCHANGE RATES, 1971-1983

COUNTRY/REGION	1972	1975	1980	1981	1982	1983
CONSUMPTION						
WESTERN WORLD	6432.0	5977.0	7203.3	7315.8	7017.0	6999.3
USA	1960.7	1468.0	1996.1	2010.7	1697.3	1753.2
FRANCE	421.0	426.8	390.1	403.8	401.9	368.8
ITALY	275.6	286.6	359.0	351.5	333.6	319.2
UK	505.5	461.7	384.8	340.9	323.3	316.8
GERMANY, F.R.	699.4	653.4	679.0	701.7	691.5	661.4
JAPAN	965.8	895.6	1013.0	1155.0	1167.9	1117.7
BRAZIL	95.0	153.2	235.1	171.0	200.1	180.0
CHINA	249.9	283.4	360.5	373.2	384.1	387.3
KOREA, REP.	6.8	40.4	100.4	115.3	121.3	142.2
MINE PRODUCTION						
WESTERN WORLD	5605.2	6238.3	6204.0	6215.8	6471.0	6551.3
USA	1348.4	1418.9	1063.3	955.4	1112.8	1110.8
CHILE	714.4	891.0	1094.5	1123.5	1178.8	1247.4
PERU	228.9	192.9	362.3	362.1	364.0	362.7
ZAIRE	446.0	550.3	430.3	467.4	478.2	493.4
ZAMBIA	728.7	700.0	594.8	591.1	580.2	547.5
REFINED COPPER OUTPUT						
WESTERN WORLD	6165.7	6773.4	6893.9	6991.2	7266.2	7403.1
USA	1798.8	1802.1	1571.0	1526.5	1641.9	1626.1
PRICES (US DOLLARS)						
USA	1325.1	1384.4	1688.1	1784.9	1906.0	2045.6
LME	1490.8	1057.3	1562.3	1715.2	1801.4	1884.4
TOTAL STOCKS	343.8	1705.5	359.3	218.9	508.4	897.7

TABLE 6.9: CASE D - SIMULATION RESULTS WITH THE 1984-ADJUSTED EXCHANGE RATES, 1971-1983

COUNTRY/REGION	1972	1975	1980	1981	1982	1983
CONSUMPTION						
WESTERN WORLD	6435.0	5988.5	7176.9	7350.3	7060.4	7013.6
USA	1943.0	1430.0	1942.1	2013.5	1715.0	1753.4
FRANCE	421.0	426.8	390.1	403.8	401.9	368.8
ITALY	277.2	289.4	361.5	353.2	334.4	319.4
UK	509.8	469.3	389.4	344.0	324.7	317.3
GERMANY, F.R.	701.4	668.2	686.0	711.3	698.3	664.5
JAPAN	973.5	925.3	1033.0	1176.1	1179.5	1121.8
BRAZIL	95.8	153.9	236.9	171.7	200.4	180.0
CHINA	251.8	290.0	365.2	378.2	388.0	389.7
KOREA, REP.	8.0	40.8	101.0	115.6	121.4	142.2
MINE PRODUCTION						
WESTERN WORLD	5699.1	6107.6	6183.8	6205.8	6459.3	6541.5
USA	1430.1	1337.7	1061.6	954.0	1106.3	1105.2
CHILE	714.4	891.0	1094.5	1123.5	1178.8	1247.4
PERU	223.5	191.3	359.8	350.7	363.5	362.7
ZAIRE	444.8	544.9	428.0	465.7	477.3	493.1
ZAMBIA	725.3	698.3	592.4	589.8	579.8	547.5
REFINED COPPER OUTPUT						
WESTERN WORLD	6280.7	6554.9	6831.3	6959.3	7243.7	7382.4
USA	1878.3	1693.3	1549.0	1516.1	1632.4	1617.2
PRICES (US DOLLARS)						
USA	1500.6	1096.1	1585.3	1782.8	1906.8	2015.1
LME	1402.5	1024.4	1481.6	1666.2	1782.0	1883.3
TOTAL STOCKS	452.8	1705.5	496.9	295.8	530.3	891.8

price is fixed at a 7% premium over the LME price, the higher average price obtained in case D allows a smaller fall in US mine output than in case C. At the same time, however, the higher US producers' price affects total US consumption which in case D is 0.9% lower than the actual observed total. This reduced total consumption leads to lower net imports by the United States and results in a lower LME price. With a lower LME price in case D than in case C, the increase in production volume and value for the developing countries is correspondingly lower in case D. The net effect of the higher US producers' price under case D is reflected in the impact on world production and consumption. In volume terms, the 1.1% decline in western world mine production is accompanied by a 2.3% fall in consumption. In value terms, the decreases in western world mine production and consumption are 2.3% and 3.8% respectively.

So far the analysis of the 1984-adjusted exchange rates effects have been in terms of US dollars. When these effects are considered in terms of the domestic currencies of the countries concerned, as in Table 6.10, a very different picture emerges. This is particularly so for the major developing country producers and the EC-4 consuming countries.

For the major developing country producers, Table 6.10 shows that the local currency values of their increased mine production is markedly higher than when valued in US dollars. The sharpest increases are for Chile and Zaire where output increases of less than 5% yield revenue increases of 135-160%.

For the major consuming countries, the consumption expenditure changes are also significantly different when valued in their local currencies. In the case of Japan, where copper consumption is relatively more price elastic than the EC-4 countries, the use of 1984-adjusted exchange rates

TABLE 6.10: EFFECTS OF 1984-ADJUSTED EXCHANGE RATES IN LOCAL CURRENCIES, 1971-1983

Variables	Actual	Case C	Case D
Mine Production			
Chile - million pesos	585.0	1409.3 (+141.0)	1379.5 (+135.8)
Peru - million sols	2011.9	2703.4 (+34.0)	2653.5 (+31.9)
Zaire - million zaires	25.5	66.0 (+159.2)	64.6 (+153.6)
Zambia - million kwachas	10.0	15.7 (+57.5)	15.2 (+51.9)
Copper Consumption			
UK - million pounds	4.4	5.2 (+19.5)	5.1 (+16.3)
Fed. Rep of Germany - million DM	34.9	47.5 (+35.8)	46.1 (+31.9)
France - million francs	39.0	57.8 (+48.3)	55.9 (+43.2)
Italy - million liras	5869.7	7874.4 (+34.2)	7668.1 (+30.6)
Japan - million yens	5676.9	5521.4 (-2.7)	5403.3 (-4.8)

Notes: Case C is with estimated US producers' price equation;
Case D is with Comex-based US producers' price equation.
Figures within parentheses denote percentage changes of the simulated from the actual values of each variable.

causes a fall in the consumption volume by 7-8%. While this lowered consumption for the 1971-1983 period leads to a fall in consumption expenditure of 7-9% in dollar terms, the reduction in consumption outlay is only about 3-5% when measured in yen.

In contrast, the EC-4 countries with their relatively price inelastic demand have to pay significantly more in local currencies for their marginally lower consumption volumes. Overall, the four EC countries reduce consumption by about 2%. However, copper expenditure valued in local currencies increases by about 16-20% for the United Kingdom, 43-48% for France, 32-37% for the Federal Republic of Germany and 30-34% for Italy.

In summary, the application of the 1984 dollar exchange rate value to the 1971-1983 period would have caused a rearrangement of production shares amongst the producing countries without significantly affecting the average LME price for the period. The major loser amongst the producing countries is the United States which, because of the exchange rate-induced loss in competitiveness, suffers production falls of up to 13% in both volume and value terms. At the global level, this production shortfall is compensated by increased production from the developing country producers whose competitiveness is enhanced by their devalued currencies. However, while their increased earnings are impressive when expressed in local currency units, they are more modest in US dollar terms. Though US mine production is reduced, US refined copper consumption is maintained through increases in copper imports. However, western world consumption is reduced because of the higher domestic prices that non-US consuming countries face. Globally, the consumption volume is reduced by some 2.5% over the entire period.

VII. ANALYSIS OF COPPER CONSUMPTION BY END-USES

7.1 Introduction

So far the consumption of copper in each country has been treated aggregatively. To capture the differential impacts of material substitution on copper consumption in the various end-uses, it is necessary to analyze copper consumption in the various end-uses separately. The estimated end-use equations are then incorporated in the model. While data on copper consumption by end-uses are not readily available, Brook Hunt and Associates (BHA) do provide data on end-use consumption for the six major OECD countries since 1968.

The BHA data for the United States, the United Kingdom, France, Italy, the Federal Republic of Germany and Japan refer to apparent copper consumption in the production of semi-fabricates, castings, salts and powders. Regrettably, this apparent consumption is defined by BHA to be the sum of consumption, imports and the direct use of scrap material, so that the apparent total consumption figures include double-counting. Since this analysis of copper demand by end-uses is based on the BHA data, the discussion of copper consumption by end-use follows the BHA-classification, which is as follows:-

1. Electrical industry.
2. Construction industry.
3. Transport industry.
4. General engineering industry.
5. Domestic and miscellaneous uses industry.

Given that the BHA copper consumption data differs from those of the World Bureau of Metal Statistics (WBMS) used in this study, some harmonization of the data is necessary. How this is done is described after the presentation of the end-use consumption equations.

In the following sections 7.2 to 7.6, the characteristics of each of the five industries listed above are discussed. The corresponding estimated end-use consumption equations are presented in Tables 7.1 to 7.5. The method of harmonizing the two sources of data and the integration of the end-use consumption equations into the model are described in section 7.7.

7.2 Copper Consumption in the Electrical Industry

In the BHA data the major sectoral end-users of copper in the electrical industry are grouped as follows:

1. Wires and Cables.
2. Telecommunications (equipment).
3. Motors and Generators.
4. Switchgears.
5. Transformers.
6. Wiring accessories.
7. Others.

The growth rate of copper consumption in the electrical industry for the six major OECD countries during the 1970s was 1.3% annually. The highest growth rate of 1.7% was achieved by Japan, while Western Europe showed a low 1.0% annual growth rate--largely because of the substitution by aluminum.

By the early 1980s, copper consumption in the electrical industry averaged about 47-49% of total copper consumed in the western industrial countries. Of this, about 77-80% derived from the wires and cables industry. Thus wires and cables remain the main outlet for copper, which is preferred for its electrical conductivity properties. For the future, copper use in this industry faces competition from a new direction--fiber optics.

TABLE 7.1: ESTIMATION RESULTS FOR COPPER CONSUMPTION IN THE ELECTRICAL INDUSTRY, 1970-1983

Country	Constant	$CRELE_{-1}$	IPI	IPIELE	$PLME_{-1}$	$\frac{1}{2}\sum_{i=1}^{2}(P^C/P^A)_{-i}$	exp^T	R^2	RHO(i)	DW	F
France	1.43 (1.0)		0.97 (3.8)		-0.09 (-1.4)			0.87		1.80	$F_{2,11}$ = 44.01
F.R. Germany	5.64 (29.8)			0.36 (8.2)		-0.28 (-6.6)	-0.03 (-10.3)	0.89	ρ (1) = -0.74 ρ (2) = -0.66	2.47	$F_{3,6}$ = 25.45
Italy	2.29 (2.0)		0.68 (2.8)			-0.16 (-2.0)		0.85	ρ (1) = 0.49 ρ (2) = -0.43	1.88	$F_{2,9}$ = 32.69
Japan	-0.81 (-1.0)		2.00 (9.1)			-0.25 (-4.8)	-0.08 (-8.8)	0.93		2.21	$F_{3,10}$ = 57.96
UK	-1.49 (-1.6)		1.65 (8.7)			-0.14 (-2.5)	-0.02 (-4.7)	0.92	ρ (1) = -0.48	1.72	$F_{3,9}$ = 46.66
US	-	0.26 (2.0)	1.38 (7.3)			-0.31 (2.6)	-0.04 (-4.5)	0.82	ρ (1) = 0.50	1.63	$F_{4,8}$ = 13.40

The specifications derived in Chapter II were used as a guide in estimating the equations for copper consumption in the electrical industry. Where an explanatory variable was insignificant, alternative variables were tried. The production indices in the OECD Industrial Production Yearbook (which uses the UN Standard Industrial Trade Classification) were used as a measure of activity in this industry. Where this activity variable failed to give significant estimates, the aggregate industrial production index was used.

Table 7.1 presents the regression results for copper use in the electrical industry. The total industrial production index was found to be a better explanatory variable than the industry-specific index (IPIELE). Consumption in Japan, the United Kingdom, and the United States is shown to be more responsive to the industrial activity level than in the other three industrial countries. The electrical industry's demand for copper is also relatively price inelastic, with long-run price elasticities of demand not exceeding 0.3. The results also indicate a secular decline in copper consumption in the electrical industries of the Federal Republic of Germany (at 3% p.a.), Japan (at 8% p.a.), the United Kingdom (at 2% p.a.) and the United States (at 4% p.a.).

7.3 Copper Consumption in the Construction Industry

In the construction industry copper is used in the production of domestic water and sanitation (DWS) tubes, builders' hardware, fittings and brassware, and water heaters. The construction industry has provided a growing outlet for copper despite wide fluctuations in the levels of home building. Copper consumption in the construction industry is related not only to new housing, but also to the level of activity in renovations, home improvements,

TABLE 7.2: ESTIMATION RESULTS FOR COPPER CONSUMPTION IN THE CONSTRUCTION INDUSTRY, 1970-1983

Country	Constant	IPI	IPICST	P^C/P^A	$\frac{1}{2}\sum_{i=1}^{2}(P^c/P^A)_{-i}$	$\exp^T$	R^2	RHO(i)	DW	F
France	44.26 (3.7)		0.47 (2.3)	11.96 (3.1)	-11.27 (-2.8)		0.67	ρ (1) = -0.48 ρ (2) = -0.58	1.83	$F_{3,7}$ = 7.76
F.R. Germany	1.31 (2.1)		0.34 (5.6)		-0.23 (-5.1)		0.73		2.25	$F_{2,10}$ =17.49
Italy	1.42 (1.0)	0.64 (2.0)			-0.13 (-1.6)	-0.02 (-2.5)	0.82	ρ (1) = 0.26	1.90	$F_{2,10}$ =28.72
Japan	-7.34 (-6.0)		0.96 (10.0)		-0.09 (-1.9)	+0.03 (6.4)	0.92	ρ (1) = -0.45	1.69	$F_{3,8}$ = 48.27
UK	-		1.12 (28.6)		-0.13 (-2.3)	-0.02 (-2.9)	0.87	ρ (1) = 0.52	1.40	$F_{3,10}$ =27.72
US	-1.23 (-1.0)	2.11 (6.4)			-0.44 (-3.6)	-0.09 (-8.2)	0.83		1.78	$F_{3,10}$ =23.13

heat installations, as well as to the level of housing stocks. Furthermore, copper has been replacing other metals such as black iron in the construction industry.

About half of the copper consumed in this industry goes to copper tubes and fittings for water services. Water fittings of brass rod stampings is an important outlet for copper consumption also, although this use is now facing severe competition from synthetic materials such as plastics. Since little substitution is expected in the brass rod stampings, except for plastics, the outlook for copper in the construction industry remains bright. The main areas for consumption growth are in the production of copper tube and fittings for water and heating services.

The regression results for the consumption equations for the construction industry are presented in Table 7.2. For the six major consuming countries the construction activity (IPICST) was tried first. Where this failed to yield acceptable estimates, the overall index of industrial production (IPI) was used.

In general, the results confirm that copper consumption in the construction industry is dependent on the level of construction activity and the relative price of copper to aluminum (P^C/P^A)--albeit, with very low price elasticities. A secular shift away from copper is seen for Italy, the United Kindom and the United States, possibly due to the inroads being made by plastics (for which no explicit account has been taken of here). In contrast to the results for the Western industrial countries, an increase in copper consumption of 3% annually is found for Japan which also exhibits a negligible long-run price elasticity of demand. It would be interesting to ascertain if this positive trend is due to the Japanese preference for copper over other metals such as black iron.

7.4 Copper Consumption in the Transport Industry

In the transport industry, copper is used in the road, rail and water transport sectors for producing various transport equipment parts. In the road transport sector, copper is used in making car radiators, cable harnesses, starter motors, car heaters and other miscellaneous parts. In the railroad sector, copper is used for making cables, transformers, electrical motors, cooling systems and other miscellaneous parts. In the shipbuilding sector, copper is used in the making of propellors, condensors, electrical equipment and systems, sea-water trunking, deck fittings, and valves and sprinklers.

During the 1970s, copper consumption in the transport industry remained at a fairly stable share of 10-11% of total copper consumption. Some decline occurred due to the direct substitution of copper by aluminum in the making of car radiators as well as other material substitution in heaters and car electrics. But these direct and indirect losses were more than offset by the growth in the road transport sector, especially that of automobile production in Japan. In Western Europe, for example, the shift to aluminum car radiators is estimated to have led to cumulative losses of about 25,000 to 30,000 tons of copper. However, in the railroad sector, electrification of railroads and construction of rapid transit systems has brought an increased demand for copper. The 1970s also saw a boom in world shipbuilding which led to increased demand for copper.

For the 1980s and beyond, material substitution and slower growth in all transport sectors is likely to constrain the growth in copper consumption. In the road transport sector, copper use per car is likely to fall as a result of miniaturization, the trend to lighter cars for increased fuel efficiency, and the shift to aluminum radiators. But, if electric cars become more widely

TABLE 7.3: ESTIMATION RESULTS FOR COPPER CONSUMPTION IN THE TRANSPORT INDUSTRY, 1970-1983

Country	Constant	IPI	$CRTR_{-i}$	PLME	$PLME_{-1}$	$\frac{1}{2}\sum_{i=1}^{2}(P^c/P^A)_{-i}$	exp^T	R^2	RHO(i)	DW	F
France	2.21 (6.4)	0.60 (9.4)			-0.09 (-3.8)		-0.03 (-13.3)	0.96	ρ (1) = 0.10 ρ (2) = -0.82	1.86	$F_{3,8}$ = 79.09
Germany, Fed. Rep. of	4.07 (4.9)	1.06 (4.3)	-0.66 (-3.9)	-0.23 (7.0)			-0.05 (-8.4)	0.84	ρ (1) = -0.74	1.60	$F_{4,6}$ = 14.12
Italy	- -	- -	1.09 (59.7)			-0.16 (-6.0)	-0.01 (-4.9)	0.86	ρ (1) = -0.74	2.03	$F_{3,9}$ = 23.14
Japan	3.33 (4.6)	0.43 (3.0)				-0.16 (-2.6)		0.88	ρ (1) = 0.36	1.73	$F_{2,10}$ =48.03
UK	-	1.03 (26.5)		-0.11 (-2.1)				0.54	ρ (1) = 0.31	1.60	$F_{2,11}$ = 7.66
US	-	1.58 (23.9)				-0.41 (-3.1)	-0.08 (-7.7)	0.74		1.86	$F_{3,11}$ =12.80

accepted, copper use per car would increase, thereby increasing the demand for copper in this sector. Consumption in the railroad sector will be sustained or increased if rapid transit systems and/or other high-speed urban public transport systems, involving further rail electrification, become more widespread. In the next decade, it is unlikely that world shipbuilding will return to the high growth rates of the 1970s. Despite the anticipation that a greater number of smaller tonnage ships with more sophisticated technology will be produced, these are not expected to reverse the decline in copper demand by the shipbuilding sector.

In estimating copper consumption in the transport sector, only the prices of copper and aluminum were used. For the activity variable, the index of total industrial production was used throughout since no suitable aggregate transport activity index is available. The results are presented in Table 7.3.

In general, the total industrial production index was a useful explanatory variable. Demand was elastic with respect to industrial activity for the United Kingdom, the Federal Republic of Germany, the United Kingdom and the United States. The low responsiveness by Japan's industrial activity was surprising, given the growth in the Japanese automotive industry in the post-war period. In Italy's case the industrial activity index failed to yield significant coefficients, so one-year lagged consumption was used as an explanatory variable. Copper consumption in the Federal Republic of Germany showed a marked cyclical pattern that could not be explained by industrial activity nor by relative price movements. Consumption lagged two years was used to capture this cyclical behavior.

Copper demand in the transport industry was found to be price-inelastic; the highest long-run price elasticity was obtained for the United States (of -0.4). There was a trend decline in consumption in France, the Federal Republic of Germany, Italy and the United States, with the United States displaying the highest displacement rate of nearly 8% annually.

7.5 Copper Consumption in the General Engineering Industry

Copper consumed in the general engineering industry refers to the material used in the production of valves and fittings, pumps, heat exchangers (including power stations), refrigerators and air-conditioners, desalination plants, petrochemical process plants, and process equipment used in the food and beverage industries. This listing illustrates the diverse range of outlets for copper consumption in the general engineering industry. During the 1970s, the growth of copper consumption in this industry averaged 1.8% annually.

For the 1980s, the demand for copper in general engineering applications will be affected by several substitution possibilities. In refrigerators and condensers for example, copper is being displaced by stainless steel and titanium. In valves and bearings, stainless steel and aluminum are increasingly displacing copper. Since consumer goods constitute a significant share of general engineering products, copper consumption growth in this industry will also depend on the growth in consumer goods demand in the developing countries and the extent to which it offsets the saturation of demand in the industrialized countries.

Table 7.4 presents the regression results. The industry-specific activity index (IPIGE) performed relatively better than the total industrial activity index for three of the six countries. Consumption is relatively

TABLE 7.4: ESTIMATION RESULTS FOR COPPER CONSUMPTION IN THE GENERAL ENGINEERING INDUSTRY, 1970-1983

Country	Constant	IPI	IPIGE	$CRGE_{-i}$	$PLME_{-1}$	P^A_{-1}	P^C/P^A	$\frac{1}{2}\sum_{i=1}^{2}(P^C/P^A)_{-i}$	exp^T	R^2	RHO(i)	DW	F
France	–		0.14 (1.7)				20.36 (6.1)	-8.72 (-3.1)	1.30 (3.7)	0.77	ρ (1) = -0.21	2.25	$F_{4,9}$ = 10.9
F.R. Germany	2.48 (2.2)			0.40 (2.7)	-0.49 (-5.0)	0.75 (1.8)				0.80		1.85	$F_{3,9}$ = 17.51
Italy	–		0.60 (3.9)	0.42 (2.7)				-0.52 (-3.8)		0.80		1.88	$F_{3,10}$ =17.05
Japan	3.33 (4.6)	0.43 (3.0)						-0.16 (-2.6)		0.88	ρ (1) = 0.36	1.73	$F_{2,10}$ =48.03
UK	-2.79 (-2.5)	1.16 (5.5)			-0.13 (-2.6)	0.90 (4.3)				0.83	ρ (1) = 0.08 ρ (2) = -0.79	2.18	$F_{3,8}$ = 18.95
US	3.99 (5.7)		0.23 (2.3)	0.44 (3.3)				-0.68 (-7.2)	-0.05 (-7.8)	0.76	ρ (1) = -0.76 ρ (2) = -0.55	2.20	$F_{4,6}$ = 9.17

inelastic with respect to the activity level except for the United Kingdom. For Italy and the United States, consumption is jointly explained by the activity level and by lagged consumption. Here again, German consumption is cyclical and this was modelled by including consumption lagged two periods as an explanatory variable.

Copper consumption in the general engineering industry is relatively price-inelastic, the highest long-run elasticity being -0.7 for the United States. For the Federal Republic of Germany and the United Kingdom, own- and cross-price elasticities differ significantly, with the aluminum price elasticity being close to unity.

Unlike copper consumption in the other industries discussed, a declining trend is observed only for the United States; there is a positive trend in France.

7.6 Copper Consumption for Domestic and Miscellaneous Uses

This last group of copper-using industries is involved in the production of a wide variety of small consumer goods, such as household appliances, table cutlery, coinage, weaponry and pesticides. Over the past decade, this category of copper consumption has averaged about 7% of total western world copper consumption.

The largest single user of copper in this group is the domestic appliances industry which is largely located in the United States, Japan, Italy and the Federal Republic of Germany. Except for the United States, these countries are major exporters of domestic appliances. The minting of coins is also a major outlet for copper--one which is likely to expand with the trend towards replacing larger denomination paper money with coins.

Copper is also used in the defence industry. Substantial tonnages of copper were used during the Vietnam War, as well as in subsequent military conflicts elsewhere, as in the Mid-East and the South Atlantic. 1/ It is difficult to equate copper consumption with defense spending, however, as it is not known to what extent the modernization of armies, such as the updating of technology in air and naval applications, implies greater or lesser demand for copper per unit of defense spending.

Copper is also used in the production of copper salts such as copper sulphate, copper oxide and oxychloride, all of which are used in producing pesticides and fungicides. However, copper use in these areas has been declining in recent years because of the introduction of, and hence substitution by, more effective man-made pesticides.

The regression results are presented in Table 7.5. Except for the Federal Republic of Germany, the total industrial production index is significant in explaining copper demand in the domestic-use industry. Japanese consumption was found to be most responsive to changes in the industrial production index and resulting in inelastic demand with respect to price. The coefficient on the relative price variable was insignificant for the United Kingdom where there has been a significant trend towards copper use in this industry. However, this result should be interpreted with caution. UK consumption in this industry fell from 50,200 tons in 1970 to 39,400 tons in 1971 and increased gradually from the 1971 level to a maximum level of 47,900

1/ It has been estimated that during the conflict over the Falkland Islands, about 500 tons of copper were expended in the form of shell cases. The losses in aircraft and surface vessels also entailed substantial rebuilding programs, and hence increased demand for copper.

TABLE 7.5: ESTIMATION RESULTS FOR COPPER CONSUMPTION IN THE DOMESTIC USE INDUSTRY, 1970-1983

Country	Constant	IPI	$CRDU_i$	$\frac{1}{2}\sum_{i=1}^{2}(P^C/P^A)_{-i}$	exp^T	$\bar{R}^2$	RHO(i)	DW	F
France	-	0.85 (23.3)		-0.10 (-2.0)		0.78	ρ (1) = 0.60	1.58	$F_{2,4}$ = 22.07
F.R. Germany	2.75 (3.7)		0.34 (1.8)	-0.24 (-4.3)		0.70		1.93	$F_{2,10}$ = 15.31
Italy	2.50 (2.5)	0.34 (1.7)		-0.21 (-3.0)		0.84		1.62	$F_{2,11}$ = 35.16
Japan	-0.39 (-1.0)	1.13 (10.7)		-0.15 (-5.3)	-0.02 (-3.8)	0.98	ρ (1) = -0.42	2.17	$F_{3,9}$ = 235.80
UK (Linear)	-52.36 (-4.0)	0.51 (5.9)	0.30 (2.7)		1.14 (7.6)	0.77	ρ (1) = -0.45	2.72	$F_{3,8}$ = 13.86
US	0.58 (0.6)	0.87 (4.3)	0.31 (2.0)	-0.28 (-3.4)		0.76		1.88	$F_{4,8}$ = 10.74

tons in 1979. Between 1980 and 1984, consumption fluctuated between 40,000 and 46,000 tons. Given the non-availability of such disaggregated data elsewhere for cross-checking the figures, it was decided to estimate the UK equation for the period from 1971 only. The trend estimate is therefore the result of starting from the low consumption level of 1971.

7.7 Integrating End-Use Consumption Equations into the Model

It will be recalled that the BHA data differs from the WBMS data. The BHA data for copper consumption by end-uses is the sum of copper consumption, copper imports and the direct use of scrap, thus causing double-counting. Consequently, for any one of the six industrial countries analyzed, total copper consumption derived as the sum of consumption in the end-use industries is higher than copper consumption reported by the WBMS. Since the model presented in Chapter VI is based on WBMS data, and since copper consumption for the United States, the United Kingdom, France, Federal Republic of Germany, Italy and Japan are disaggregated in the model, adjustments to ensure data consistency were necessary.

The method used to correct for the double-counting in the BHA data is simple regression of the BHA-based total consumption on WBMS-based total consumption. These simple regression equations, for which estimates are presented in Table 7.6, provide the adjustment link between the BHA-based end-use consumption equations and the WBMS-based aggregate consumption equations used in the model simulations reported earlier. The total consumption estimated by aggregating the five end-uses based on BHA data is labelled with the suffix "EST" to distinguish it from aggregate consumption based on the WBMS data.

TABLE 7.6: EQUATIONS LINKING THE AGGREGATED END-USE CONSUMPTION TO TOTAL CONSUMPTION VALUES, 1970-1983

Country	Constant	CR_{-1}	CREST	$\bar{R}^2$	RHO(i)	DW	F
France		0.20 (1.2)	0.60 (4.7)	0.67	ρ (1) = 0.95 ρ (2) = -0.64	2.07	$F_{2,10}$ = 11.45
F.R. of Germany		0.27 (2.0)	0.72 (5.5)	0.44	ρ (1) = 0.55	1.87	$F_{2,11}$ = 5.27
Italy	162.01 (4.0)		0.31 (4.0)	0.87	ρ (1) = 1.17 ρ (2) = -0.47	2.03	$F_{1,10}$ = 75.21
Japan	-192.52 (-1.5)		0.96 (10.0)	0.93	ρ (1) = 0.45	1.79	$F_{1,11}$ = 158.32
UK	-		0.82 (13.1)	0.91	ρ (1) = 0.90	2.02	$F_{1,14}$ = 136.63
US	27.42 (0.1)		0.77 (9.2)	0.86		2.12	$F_{1,12}$ = 83.76

Notes: CR Denotes total consumption based cn WBMS data.
CREST Denotes estimated aggregated end-use consumption based on BHA data.

After incorporation of the end-use data, the model was validated for the period 1971-1983. The model tracks the historical period relatively well, yielding solutions that are similar to those reported in Chapter VI. With the end-use disaggregation of copper consumption, the model can be used to simulate alternative scenarios regarding differential rates of material substitution in the various end-uses such as the outlook for the potential inroads by fiber optics described in the next chapter.

VIII. FIBER OPTICS AND LONG-TERM COPPER MARKET PROSPECTS

8.1 Advantages of Fiber Optics

In analyzing the prospects for copper it is necessary to consider, inter alia, material substitution by traditional and/or newer materials. One new material that has been receiving much attention for its potential impact on the telecommunications industry, and hence on copper, is that of fiber optics.

The advantages of using fiber optics in telecommunications are as follows (Douglas, 1982; Tan, 1986):

1. Fiber optics has a higher carrying capacity through a larger bandwidth that allows many more voice channels than copper coaxial cables. Currently, a single fiber can transmit 10,000 voice channels compared with 3,600 voice channels for a copper wire.
2. Low loss of frequency power, from a few decibels per kilometer to less than 0.5 decibels/km. The low loss of frequency power means that fewer repeater stations are required than is the case with copper cables. Copper cables require repeaters every 1.5 km., while fiber optics require repeaters only every 15 km to 20 km. Recently, British Telecom has shown that technically a 100 km. long link without a repeater is possible.
3. Technological superiority in digital transmissions. Technologically, fiber optics is amenable to the digital transmission of voice, data or video on the same fiber. The telecommunications industry is in the process of switching to

all digital systems, and fiber optics-based lightwave transmission is ideally suited to this technology.

4. Small size, lightweight and ease of installation. Because of its small size and light weight, fiber optics offers the advantage of ease of handling and installation in urban ducts where capacity is fully utilized. Instead of digging up streets to install larger ducts so as to expand the transmission capacity the existing copper cable is currently being replaced with fiber optics transmission capacity.

5. Immunity from radiation and electromagnetic or radio frequency interference such as from lightning, crosstalk, motors or power lines. This immunity makes it possible, for example, to install fiber optics cable in the San Francisco Bay Area Rapid Transit subway beneath the San Francisco Bay. The cable connects San Francisco with the cities on the east side of the bay. The immunity of fiber optics to electrical interference also makes it possible to place fiber obtics cables alongside power lines, which will enable utilities to use these rights of way to integrate their power stations, distribution stations and main offices into a private communications network.

6. Fiber optics also has the advantage of being difficult to tap without a high degree of skill.

7. Fiber optics has the property of nonconductivity and does not have ground loop problems.

8. Fewer splices are needed for fiber optics because of the fewer repeater stations required.

9. Fiber optics require less maintenance and are more energy efficient.

10. Fiber optics have lower cost.

Many of these properties make fiber optics highly attractive for use in military applications.

8.2 Fiber Optics and the Telecommunications Industry

The recent dynamic growth of the telecommunications industry has taken the form of development of linkages between firms that make the hardware (computers, telephones and all the ancillary equipment) with those that supply the data and information. The prospects for fiber optics in the United States are now particularly bright because of the deregulation of the US telephone industry which is providing new marketing opportunities for old as well as recently-established companies.

The telecommunications market consists of three main sectors:

(1) telephones

(2) telegraph

(3) cable televison or cablevision.

In both the private and public telephone and telegraph sectors, there has been rapid adoption of private communications networks. Such private networks take the form of inter-office links by means of telephone, videophones or teleconferencing and data transmission. Teleconferencing is a particularly effective means of putting geographically-scattered groups together with immense savings on travel and expenses.

Telecommunications serve basically two broad areas: intra-city and inter-city communications. Intra-city telecommunications include inter-office trunking for telephones, in-building wiring and subscriber networks (or loops), and cellular radio by which telephone service is provided by radio phone receiving and broadcasting within cells to other phones either within the cell or to other cells.

Intercity telecommunications link major urban areas and include telephone cables of either copper, aluminum, fiber optics, microwave or satellite. Fiber optics therefore competes with satellites, telephone cables and microwave for transmission of large quantities of data. The advantage of fiber optics to these other systems is that it can handle more voice channels or data without interference.

Another area where fiber optics competes with copper is in the undersea cable where fiber optics' high circuit capacity, multiple media choice and cost economies make fiber optics systems very competitive even with satellites. Thus fiber optics might become the preferred carrier between continents; some analysts predict that by the early 1990s, fiber optics will totally displace copper undersea cable.

8.3 Impact of Fiber Optics on Copper Market Prospects

Fiber Optics has often been cited as a material that is likely to make rapid inroads into the telecommunications industry, and therefore to have a significant impact on the copper market. The copper model has been used to simulate scenarios reflecting fiber optics adoption so as to assess the potential impact of fiber optics on the copper market. Before introducing fiber optics, the model was first simulated for long-term projections under given assumptions regarding the exogenous variables to provide a base case for evaluating the impact of fiber optics.

8.3.1 Assumptions for Long-Term Projections

Before describing the long-run projections produced by the model, the assumptions about the prospects for the exogenous variables are first described. Each set of exogenous variable projections for the period 1985-95 is defined primarily by the rates of GDP growth of the copper-consuming countries and the rates of inflation in the consuming and producing countries. Projections of exchange rate movements of individual currencies vis-a-vis the US dollar are also necessary.

Table 8.1 presents the base-case GDP growth rates assumed for the industrial countries for the period 1985-95. The projected rates of growth of industrial production are derived on the basis of their correlation with GDP in the historical period. The scenario adopted here, while believed to be consistent in its assumptions, is not necessarily one which would be adopted by the World Bank.

Several price indices are also used in the model. For most of the countries included, their consumer price index (CPI) and exchange rate against the US dollar are required to derive the LME price in domestic currency. Since the assumptions about inflation are given in terms of the GDP deflator, the GDP deflator (in local currencies) is used to estimate the CPI. These estimates are then used to obtain the CPI projections. The various inflation rate projections are presented in Table 8.2. The exchange rate projections for each country have been made on the basis of the differentials between the GDP deflator measured in US dollars and in local currency. The GDP growth rates for the remaining countries are presented in Table 8.3.

TABLE 8.1: PROJECTED ANNUAL RATES OF GROWTH OF GDP, INDUSTRIAL COUNTRIES: 1985-1995
(% per annum)

Year	North America	Western Europe	Japan
1985	3.0	2.5	4.9
1986	2.0	2.4	2.8
1987	4.2	2.4	4.3
1988	3.3	2.5	3.9
1989	3.3	2.6	3.9
1990	3.3	2.7	4.0
1991	3.5	2.8	4.2
1992	3.5	2.9	4.2
1993	3.5	3.0	4.2
1994	3.5	3.0	4.2
1995	3.5	3.0	4.2

TABLE 8.2: INFLATION RATE PROJECTIONS: 1985-1995

Year	GDP Deflator: USA	GDP Deflator: Western Europe	GDP Deflator: Japan
1985	3.5	4.4	1.6
1986	5.0	4.0	2.0
1987	5.5	4.0	2.5
1988	5.5	4.0	2.5
1989	5.5	4.2	2.5
1990	5.5	4.5	2.5
1991	5.0	4.5	2.5
1992	5.0	4.5	2.5
1993	5.0	4.5	2.5
1994	5.0	4.5	2.5
1995	5.0	4.5	2.5

TABLE 8.3: PROJECTED ANNUAL RATES OF GROWTH OF GDP, DEVELOPING COUNTRIES: 1985-1995
(% per annum)

Regions	1985-1990	1990-1995
Developing Countries	5.0	5.1
Low Income Countries	5.4	5.2
Africa	3.1	3.4
Asia	5.6	5.3
Middle Income Countries	4.9	5.1
Oil Importers	5.1	5.4
Oil Exporters	4.4	4.5
High Income Oil Exporters	4.6	4.4

8.3.2 Base Case Projections

The model was simulated for the 1985-1995 period on the basis of the exogenous variables set out above. The results for the key variables are summarized in Table 8.4.

In the base case projections presented in Table 8.4, mine capacity in the market economies is projected to grow from 7.6 million tons in 1984 to 7.9 million tons in 1990, and then stabilize at 7.8 million tons by 1995. Of the major producing countries, Chile's mine capacity is projected to rise from 1.3 to 1.7 million tons during the 1984-95 period. Other countries with mine capacity expansions not exceeding 0.1 million tons over the 1984-1995 period are Canada, Mexico, Peru, Australia and Papua New Guinea. In contrast, US mine capacity is projected to decline from 1.6 to 1.1 million tons between 1984 and 1995. Other countries with declining or stagnant mine capacities during the projection period are Mexico, Zambia, Zaire, South Africa and the Philippines.

TABLE 8.4: SUMMARY OF BASE CASE PROJECTIONS FOR THE COPPER MARKET WITHOUT FIBER OPTICS, 1984-1995 (MILLION TONS)

VARIABLE	1984	1990	1995
Mine Capacity	7.60	7.90	7.80
Mine Production	6.70	7.00	7.20
Refined Copper Production	7.50	8.34	8.79
Refined Copper Consumption	7.60	8.53	9.31
Substitution by Fiber Optics	0.00	0.00	0.00
Net Imports from Comecon	0.13	0.12	0.12
LME Price - Current $/ton	1378.00	2382.00	3345.00
- 1985 $/ton	1354.00	1650.00	1860.00

Notes: (1) Mine capacity is given in million tons per year at the beginning of the year.
(2) Production and consumption figures are in million tons of refined copper.

Based on these mine capacity projections, world mine production will rise from 6.7 million tons in 1984 to 7.0 and 7.2 million tons by 1990 and 1995 respectively. This, together with scrap recovery, will yield a world refined copper production of 8.3 and 8.8 million tons by 1990 and 1995 respectively. With world refined copper consumption projected to rise from 7.6 million tons in 1984 to 9.3 million tons by 1995, the nominal LME price is projected to rise to $2382 per ton in 1990 and $3345 per ton in 1995. In 1985 dollars, the corresponding prices will be $1650 and $1860 respectively.

8.3.3. Fiber Optics Scenarios

One view concerning the rate of fiber optics adoption is that of Brook Hunt and Associates (BHA). In their mid-1984 quarterly review (Brook Hunt and Associates, 1984) the forecast is made that fiber optics will have displaced 40% of the copper consumed in the telecommunications industry by

1990. This forecast concurs with the rates of copper displacement presented by Douglas (1982) for the telecommunications industry of the United States, the United Kingdom, France, Federal Republic of Germany, Italy and Japan. The accelerated rates of displacement considered most likely by Douglas and BHA in these six countries are as follows:-

Year	Rate of Fiber Optics Adoption (% p.a.)
1983	3.2
1984	6.2
1985	10.0
1986	15.0
1987	20.1
1988	25.2
1989	32.0
1990	40.0
1991	46.0
1992	51.0
1993	58.0
1994	64.0
1995	70.0

To estimate the volume of copper that will be displaced by fiber optics at the rates of displacement given above, it is necessary to derive coefficients for the downward adjustment of copper consumption in the electrical sector. This is done by taking into account copper consumption in the telecommunications industry as a share of consumption in the electrical sector (R1), and electrical sector consumption as a share of total consumption (R2). The assumed rates of copper displaced by fiber optics (FODR), the relative shares of consumption (R1 and R2) and the adjustment coefficients (FOCOEFF) used to calculate the lower copper consumption due to fiber optics penetration are summarised in Table 8.1 for the six industrial countries where fiber optics is expected to have its major impact. The copper displaced by fiber optics is the difference between copper consumption before and after the application of the adjustment coefficients. The volume of copper displaced in each country is dependent on both the share of copper consumed by telecommunication cables in the electrical sector, and the share of electrical sector consumption to total consumption. Table 8.5 shows a gradual decline in the shares of copper consumption in the electrical sector, as reflected in the adjustment coefficient.

Assuming the GNP growth rates and fiber optics penetration rates described above, the model simulation results in Table 8.6 suggest that consumption in the Western world could grow from 7.6 million tons in 1984 to 8.3 and 9.0 million tons in 1990 and 1995, respectively. These results are based on the assumption of copper displacement by fiber optics in the telecommunications industry at the rates presented above. About 230,000 tons of copper would be displaced in the six major OECD countries by 1990 and 310,000 tons by 1995. The mine capacity and production assumptions are the same as in the base case. The quantity of copper displaced by fiber optics during the 1985-1995 period for the six industrial countries is given in Table 8.7. Of the total of 310,000 tons of copper displaced by fiber optics in these six countries by 1995, the largest losses are incurred in Japan and Italy. Copper consumption in these countries suffers most because they presently have the largest shares of copper consumption in both the telecommunications and electrical industries. The forecasts of the rate of adoption of fiber optics technology do not take account of expected use of fiber optics technology in other countries or in other industries in the six industrial countries, and therefore have to be seen as conservative estimates of the eventual loss by the copper market to fiber optics competition.

TABLE 8.5: COEFFICIENTS USED TO CALCULATE COPPER DISPLACEMENT BY FIBER OPTICS IN SIX INDUSTRIAL COUNTRIES, 1983-1995

	FRANCE			
	FODRFRA	R1FRA	R2FRA	FOCOEFFFRA
1983	3.20	14.19	55.00	1.000
1984	6.20	13.31	54.52	0.991
1985	10.00	11.98	53.79	0.978
1986	15.00	10.18	52.82	0.960
1987	20.10	8.04	51.75	0.941
1988	25.20	6.01	50.76	0.923
1989	32.00	4.09	49.79	0.905
1990	40.00	2.45	49.25	0.896
1991	46.00	1.37	48.72	0.886
1992	51.00	0.67	48.53	0.882
1993	58.00	0.28	48.34	0.879
1994	64.00	0.10	48.25	0.877
1995	70.00	0.03	48.22	0.877
	GERMANY, F.R.			
	FODRWG	R1WG	R2WG	FOCOEFFWG
1983	3.20	16.20	46.30	1.000
1984	6.20	15.68	46.05	0.995
1985	10.00	14.71	45.60	0.985
1986	15.00	13.24	44.93	0.970
1987	20.10	11.25	44.04	0.951
1988	25.20	8.99	43.05	0.930
1989	32.00	6.73	42.08	0.909
1990	40.00	4.58	41.18	0.889
1991	46.00	2.75	40.43	0.873
1992	51.00	1.48	39.92	0.862
1993	58.00	0.73	39.62	0.856
1994	64.00	0.31	39.45	0.852
1995	70.00	0.11	39.37	0.850
	ITALY			
	FODRITA	R1ITA	R2ITA	FOCOEFFITA
1983	3.20	17.73	62.65	1.000
1984	6.20	16.63	61.96	0.989
1985	10.00	16.00	61.57	0.983
1986	15.00	13.60	60.09	0.959
1987	20.10	10.87	58.45	0.933
1988	25.20	8.13	56.85	0.907
1989	32.00	5.53	55.37	0.884
1990	40.00	3.32	54.15	0.864
1991	46.00	1.79	53.32	0.851
1992	51.00	0.88	52.83	0.843
1993	58.00	0.37	52.56	0.839
1994	64.00	0.13	52.43	0.837
1995	70.00	0.04	52.38	0.836

NOTES:
- FODR - Rate of copper displacement by FO;
- R1 - Copper consumption in telecommunications as a share of copper consumption in electrical ind
- R2 - Copper consumption in electrical industry as a share of total copper consumption;
- FOCOEFF - Coefficient used to obtain copper consumption substitution by FO.

TABLE 8.5: continued

JAPAN	FODRJAP	R1JAP	R2JAP	FOCOEFFJAP
1983	3.20	10.06	64.54	1.000
1984	6.20	9.44	64.13	0.994
1985	10.00	8.49	63.52	0.984
1986	15.00	7.22	62.71	0.972
1987	20.10	5.77	61.80	0.958
1988	25.20	4.32	60.90	0.944
1989	32.00	2.94	60.06	0.936
1990	40.00	1.76	59.33	0.919
1991	46.00	0.95	58.94	0.913
1992	51.00	0.47	58.65	0.909
1993	58.00	0.20	58.49	0.906
1994	64.00	0.07	58.42	0.905
1995	70.00	0.02	58.39	0.905

UK	FODRUK	R1UK	R2UK	FOCOEFFUK
1983	3.20	15.40	50.50	1.000
1984	6.20	14.91	50.25	0.995
1985	10.00	13.90	49.74	0.985
1986	15.00	12.58	49.08	0.972
1987	20.10	10.69	48.15	0.954
1988	25.20	8.54	47.11	0.933
1989	32.00	6.39	46.10	0.913
1990	40.00	4.35	45.16	0.894
1991	46.00	2.61	44.37	0.879
1992	51.00	1.41	43.84	0.868
1993	58.00	0.69	43.52	0.862
1994	64.00	0.29	43.34	0.858
1995	70.00	0.10	43.26	0.857

USA	FODRUSA	R1USA	R2USA	FOCOEFFUSA
1983	3.20	2.80	50.50	1.000
1984	6.20	2.71	50.45	0.999
1985	10.00	2.54	50.36	0.997
1986	15.00	2.28	50.22	0.995
1987	20.10	1.95	50.05	0.991
1988	25.50	1.55	49.85	0.987
1989	32.00	1.16	49.66	0.983
1990	39.00	0.78	49.47	0.980
1991	46.00	0.47	49.32	0.977
1992	51.00	0.26	49.22	0.975
1993	58.00	0.13	49.16	0.973
1994	64.00	0.06	49.12	0.973
1995	70.00	0.02	49.10	0.972

NOTES:
- FODR - Rate of copper displacement by FO;
- R1 - Copper consumption in telecommunications as a share of copper consumption in electrical ind
- R2 - Copper consumption in electrical industry as a share of total copper consumption;
- FOCOEFF - Coefficient used to obtain copper consumption substitution by FO.

Taken together with projected net imports of refined copper from the CPEs of 120,000 tons annually throughout the period 1985-1995, the supply-demand scenario outlined above would yield nominal price projections of $2,116 per ton (96¢/lb) and $2,989 (136¢/lb) per ton refined copper in 1990 and 1995 respectively. In 1985 dollars, these translate into $1,432 (65¢/lb) and $1,630 (74¢/lb) in 1990 and 1995, respectively. Comparing these price projections with those projected without fiber optics substitution, the fall in copper price due to fiber optics penetration into the telecommunications industry are 11.2% and 10.6% in nominal terms for 1990 and 1995 respectively. In 1985 dollars, the price declines are 12.6% and 12.4% for 1990 and 1995 respectively.

TABLE 8.6: SUMMARY OF BASE CASE PROJECTIONS FOR THE COPPER MARKET WITH FIBER OPTICS, 1984-1995

Variable	1984	1990	1995
Mine Capacity	7.60	7.90	7.80
Mine Production	6.70	7.10	7.20
Refined Copper Production	7.50	8.30	8.80
Refined Copper Consumption	7.60	8.30	9.00
Substitution by Fiber Optics	0.00	0.23	0.31
Net Imports from Comecon	0.13	0.12	0.12
LME Price - Current $/ton	1378.00	2116.00	2989.00
- 1985 $/ton	1354.00	1432.00	1630.00

Notes: (1) Mine capacity is given in million tons per year at the beginning of the year.
(2) Production, consumption and fiber optics substitution figures are in million tons of refined copper.

TABLE 8.7: COPPER DISPLACED BY FIBER OPTICS IN SIX OECD COUNTRIES, 1984-1995
('000 tons)

Year	France	Fed. Rep. of Germany,	Italy	Japan	United Kingdom	USA
1984	2.5	1.8	3.1	4.9	0.9	1.2
1985	6.4	5.2	4.8	12.0	2.9	3.8
1986	11.9	9.0	11.6	20.4	5.6	7.9
1987	18.4	14.8	20.0	31.1	9.7	12.8
1988	24.9	21.1	28.0	41.6	14.6	18.9
1989	31.6	25.5	35.9	51.7	19.9	25.0
1990	36.1	31.5	43.0	60.7	25.2	31.6
1991	40.8	37.2	48.6	66.1	30.4	36.3
1992	43.4	39.3	52.5	70.4	34.6	40.3
1993	45.9	41.2	55.6	72.9	37.9	42.6
1994	47.8	50.8	57.8	74.5	40.5	43.9
1995	49.3	50.7	59.4	75.5	42.6	44.4

IX. DISCUSSION AND CONCLUSIONS

9.1 Important Features of the Copper Model

This paper describes the structure and presents the estimated equations of an econometric model of the western world copper market. The model, which is disaggregated by the major consuming and producing countries, is based on annual data for the 1964-1983 period. While a major reason for estimating the model is to provide a framework for long-term projections, an attempt was also made to specify the model so as to allow its use for assessing structural change during the estimation period. In specifying the model it was also necessary to take into account the shift in US producers' pricing from a unified list price to pricing based on the Comex (and hence LME) price after 1978.

The model is essentially a supply-demand model that is closed via the stocks balance identity. Primary supply (or mine production) was estimated separately for the major producing countries, with the mine capacity explanatory variable treated exogenously. Since the world price of copper refers to refined copper, it was necessary to estimate an equation to explain refined copper supply; this was derived as the sum of primary refined copper, which is derived from mine production, and secondary refined copper supply which is recovered from old scrap. The US supply equation was modified to account for stockholding behavior at the primary supply level, in anticipation of the periodic mineworkers' strikes, and for the net imports of copper.

Separate consumption equations were estimated for the major consuming countries. Refined copper consumption was explained primarily by the level of industrial output. For some of the industrial consuming countries, a marked secular decline in copper consumption was observed. This is believed to be due to substitution by other materials whose prices are not incorporated in model estimation and to technical change, including the recent influence of miniaturization.

Although the model relates to the western world copper market, the net exports of the Comecon countries to this market have to be taken into account, since these exports increase western world copper availability. The US trade in copper is also analysed as it provides the nexus between the US and non-US markets through which the changing structural relationship between the two markets is observed and analysed. From the US net copper imports equations it can be seen that while net refined copper imports were greater, the higher the US domestic producers' price was above the world price, the reverse was true for net imports of unrefined copper. This relationship reflects the higher production costs in the United States. The ability of the US industry to maintain higher US producers' price for so long was due to vertical integration in the domestic US copper industry which granted a captive market to the domestic industry for the higher-priced domestic copper.

From the estimated equation for the world price it was found that apart from the level of stockholdings and the ratio of copper consumption to copper availability, price was also influenced by exchange rate variations and inflation. Two alternative specifications were derived to explain the US producers' price. The simulation results verified that this was necessary as the pricing behavior in the pre-1978 and post-1978 periods was different. In the pre-1978 period, unified list pricing reflected the dominant position of the vertically-integrated US copper industry in the world market. The domestic producers' price was not systematically related to, nor consistently higher than, the world price--as is the case in the post-1978 period. Rather, it was influenced by consideration of supply accessibility to deter substitution by domestic consumers. The shift of domestic producers' pricing to one linked with the world price, albeit with a premium, in the post-1978 period reflects pressure on US producers to integrate into the world market in a period of declining comparative advantage.

9.2 Empirical Findings from the Copper Model

As in many other studies of the copper market (albeit covering different time periods) this study found price elasticities of primary and secondary supply and demand to be very inelastic.

For primary or mine production, the short-run elasticity of supply with respect to price for the 1964-1983 period was found to be in the range zero to 0.35--even lower than the 0.51 estimated by Wagenhals (1983). The price elasticity for secondary supply was similar (less than 0.5), with supply adjusting to desired production in about 6 months. Koss (1985) and Richard (1978), using annual and quarterly data respectively, found that production adjusts to the desired production level in 3-5 months. 1/ This suggests less-than-full capacity utilization which is indicated by the mine capacity coefficients of less than unity found in this study.

1/ From their continuous-time model estimates, Koss (1985) and Richard (1978) found that adjustment in the copper market to any shock tends to be fairly rapid. In general, consumers adjust to market changes within 4-8 months. Overall, the market has a strong tendency to return to its equilibrium path when disturbed, with the long-term adjustment taking some 3-3½ years (Koss, 1985).

Demand was found to be fairly price inelastic with own or relative price elasticities not exceeding -0.25 in the short run and less than -0.60 in the long run. These estimates are similar to those estimated in other studies. Demand for copper was found to be determined primarily by the level of industrial activity or income. The estimates for the 1968-1983 period show that the elasticity of response in copper consumption to industrial activity varied from a low of around 0.4 for countries such as France, the Federal Republic of Germany and Japan, to a high of 1.5 to 1.7 for countries such as Brazil, the United Kingdom and the United States. These estimates are comparable to income elasticities of demand of 0.5-1.1 estimated by Koss (1985), Richard (1978) and Wagenhals (1983).

These cross-country differences in copper consumption elasticities with respect to industrial production (γ^{IPI}) led to a comparison of these elasticities with their materials intensity of GNP measures. By examining the elasticity estimates in conjunction with the intensity-of-use (IOU) of copper with respect to GNP for the consuming countries, it is found that countries with low γ^{IPI} have high IOUs (such as the Federal Republic of Germany and Japan) and vice versa (such as the United States and Brazil). While in-depth examination of these behavioral differences lies beyond the scope of this study, an intuitive explanation based on inter-country differences in the relative shares of copper-using industrial product in total industrial product suggests itself. That is, countries with high γ^{IPI} but low IOU would have relatively smaller shares of copper-using industrial production out of their total industrial production than countries with low γ^{IPI} and high IOU. In other words, beyond the IOU measure, it is necessary to know how the composition of industrial production within and between countries is changing if the evolving copper demand patterns in the industrial countries are to be better understood. The inadequacy of the IOU measure as a means to understand the cross-country differences in their evolving patterns of materials demand has been criticized by Auty (1985) who shows that "Upon closer inspection the basic concept (IOU) is.....vaguely defined." Auty concludes that "Further research is required using input-output models to trace the impact of technological change on materials consumption for economies at differing levels of development and with differing industrial structures."

Measurement of the impact of factors affecting the copper price showed that a 1% increase in excess demand would result in a 2% increase in price; this result compares with a figure of 1% estimated by Richard (1978) and 1.8% estimated by Koss (1985). The influence of interest rates on price formation could not be established in this study. However, Koss (1985) found the real interest rate to be a significant price determinant; a 1% increase in the real interest rate was found to cause a 1.9% price increase. However, the estimated coefficient on the real interest rate has a low t-value, which Koss attributed to the volatility of the copper price as compared to the stable real interest rate. The estimated coefficient for the impact of a change in the real exchange rate indicates that a 1% increase in the real sterling-dollar rate (i.e. a fall in the value of pound sterling) would lead to a 2.5% increase in the LME price quoted in sterling pounds per ton. While this may seem unduly high, similar values were obtained by Gilbert (1986) whose explanation is couched in terms of the debt problem and debt servicing requirements of the primary commodity producing developing countries. A fall in the dollar price of a commodity would induce exporting countries to increase their exports so as to maintain their export revenues and to service their debts. This rise in commodity exports causes a secondary fall in the dollar price of the commodity so that the total impact of a dollar appreciation is a relatively higher fall in the commodity's dollar price. For the impact of inflation, a 1% rise in inflation will cause a 1.3% increase in the LME price.

9.3 Some Implications of the Results

Some implications may be drawn from the estimated elasticities pertaining to demand and supply, the influence of exchange rate variations, the role of US trade in copper, and the likely competition from new material substitutes.

The price inelasticities found for both primary and secondary copper supply reinforce the importance of sound copper investment appraisals because of the long gestation period and production lifespan associated with such investments. These low supply elasticities are manifest in the surplus supply situation in the recent prolonged recession, which has given rise to allegations of oversupply financed through public subsidies to parts of the copper industry. In retrospect, the severity of the recent depressed market may be seen as an attestation not only of (i) the interdependence of investment decision-making, but also of (ii) the pivotal role of perceptions of market developments. The expectation that the impressive growth in copper consumption in the 1960s would continue throughout the 1970s and beyond proved unrealistic. Also, the perception by some copper producers that nationalization of the industry in some of the developing producing countries would lead to a loss in their competitiveness proved only partially correct. The present surplus capacity is thus the result of investment coming onstream as demand became stagnant. The low supply elasticities and the 3-4 year period required to return to an equilibrium path after a shock further highlights the importance of production cost variations among the locationally-disperse producers. This is because producers with lower cash (production) costs will, generally speaking, have the advantage of adjusting faster to the new equilibrium position. These production cost variations also highlight the need for continuous efforts by producers working with deposits of declining ore grade to increase productivity (to offset the higher production cost due to the declining ore grades) and remain competitive. When the ore grade is very low in comparison with ore grades of other producers, it raises the question of choice between new investment and investment to increase efficiency in extraction and refining to offset the declining ore grades. However, while it may seem appealing to attempt theoretical delineation of that level of ore grade below which a producer should consider investment in a new mine, such delineation is practically unwieldy, if not impossible. This is because of the sequential processing required to convert the ore to its concentrate and then refined form, and the differential effective rates of infrastructure depreciation at each processing stage and over the course of the mining operation. Hence, to evaluate whether to shift from investment in the existing mine to a new mine, it is necessary to integrate analysis of the declining ore grade with that of infrastructure depreciation.

From the empirical results it was found that changes in income and industrial production influence copper consumption more than price variations. The joint consideration of the price inelasticity of, and secular decline in consumption substantiates the view that penetration of the copper market by other materials has been due more to the inadequate concern given to marketing and promotion of copper use than to price fluctuations. Simulations show that even if aluminum had been one-and-a-half-times more expensive than copper in the historical period, the increase in copper consumption would have been marginal. Instead, the higher aluminum price would have allowed higher copper prices and royalties.

Competitiveness between copper producing countries was shown to be affected by exchange rate variations. Assuming the 1984 parity exchange rates held for 1975 as well as 1980, the ranking of countries by their average net production costs (i.e., the cash cost net of byproduct/coproduct credits) are affected differentially. Of the twelve major producing countries, Chile's ranking would move from 10th in 1975 to 9th in 1980 and 6th in 1984. Zaire's ranking would move from 8th in 1975 to 2nd in 1980 to 3rd in 1984. In contrast, the ranking for the United States remained at 12th for all three years. Model simulations show that with exchange rates held at the 1984 parity level, the strong dollar value would cause developing countries to respond with increased production that would yield earnings that are proportionately higher in domestic currencies than in dollars.

9.4 Conclusions

In constructing an econometric model for the purpose of long-term projections, this study has shown that the copper market has undergone considerable structural change since the mid-1960s. Up to the early 1960s, the copper market was imperfectly competitive, with the United States being the single largest producer and consumer. Domestic US copper production constituted about one-third of the total world production, with the United States also having offshore copper investments as in Chile and Peru. At the same time US copper consumption was almost half of total world consumption, giving rise to an oligopolistic domestic market with a high degree of vertical integration. This provided the raison d'être for the two-price system consisting of a unified US producers' list price that was at variance with, and tended to be lower than, the world price of copper.

Various developments have precipitated the structural changes in the copper market since the mid-1960s. On the supply side, political independence and nationalization of the copper industries in the developing producing countries have led to expansion in mine capacities and lower cost outputs. This development, together with declining ore grades in the United States, led to the share of higher-cost US production falling to about 20% in 1983. The US consumption share also declined to about 22% in 1983, as consumption in Japan and the newly industrializing countries expanded. The decline in the competitiveness of US production was exacerbated by competition from the aluminum industry which further squeezed copper prices and royalties. The changes in the international monetary system and the quadrupling of oil prices in the first half of the 1970s delayed awareness of the changing market structure until the onslaught of the prolonged recession and stagnant demand for copper in the late 1970s.

The recent recession brought into focus the severity of over-investment in capacity expansions in the 1970s for a commodity whose price inelastic demand is driven primarily by industrial activity. A prolonged period of over-supply and low prices translates into reduced capacity utilization rates that adversely affect the profitability of mining operations. In the model, mine capacity is treated exogenously, with copper prices and mine capacity utilization rates providing the internal checks for consistency and feasibility of the projections.

This study has shown that structural changes in the copper market in the last 20 years arose from (1) the declining ore grades of US copper mines alongside expansion in investments in higher-grade copper mines elsewhere, (2) the increase in state participation in copper production, (3) the diversification of copper supply sources, (4) competition from material substitutes such as aluminum, plastics, fiber optics and (5) miniaturization. The decline in the comparative advantage of US production is manifested in the shift from a unified US producers' price to direct linking of US producers' price to the world price. Non-viability of continued US domestic producers' pricing independently of the world price is reflected in the growth in US refined copper imports. The model simulations indicate that improvements in the copper market outlook for the 1990s must be predicated on downward adjustments over the next 5 years of the presently non-viable excess mine capacities so that production may be brought into line with consumption during the 1990-1995 period.

By utilizing the end-use copper consumption equations for the six major industrial countries, long-term projections reflecting the impact of fiber optics substitution were assessed. When fiber optics substitution of copper in the telecommunications industry in the United States, United Kingdom, France, Federal Republic of Germany, Italy and Japan is simulated, total copper consumption is projected to be reduced by 230,000 tons by 1990 and by 310,000 tons by 1995 as compared to a simulated base case. The reduced demand for copper is projected to cause a decline in LME prices: in nominal terms, the LME price would be 11.2% lower in 1990 and 10.6% lower by 1995; in 1985 dollars, the copper price would be 12.6% lower in 1990 and 12.4% lower in 1995.

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