A SECTORALLY DISAGGREGATED ECONOMETRIC MODEL FOR FORECASTING COPPER DEMAND IN THE U.S.

by

ROBY RAJAN

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APPROVED:

ERIC L. HIRSCHHORN

DWIGHT R. LEE

HANIF D. SHERALI

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(ABSTRACT)

Copper econometric models currently existing in the open literature incorporate the demand side of the market only as an aggregated demand function. In this thesis, copper demand was disaggregated into its end-use industrial sectors and linear demand equations estimated for each sector.

The correlation among the error terms of the various sectoral equations was explicitly taken into account in the estimation. Elasticities were computed at the means for the price and activity variables. A comparison with results using the Ordinary Least Squares method is also provided.

Exogenous variables used in each sectoral equation were forecast separately and copper demand was subsequently forecast for each end-use sector.

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Chapter I

INTRODUCTION

Copper is one of the world's most important primary materials. Indeed, the total value of international trade in copper and copper-bearing materials is about $6 billion per year on the average, and is exceeded among natural resources only by the value of trade in petroleum. Copper is valued for its combination of strength, ease of forming, corrosion resistance, and thermal and electrical conductivity. Copper's low electrical resistance is its economically most important characteristic; about half of all copper consumption is in applications relying on electrical conductivity. Over the past hundred years or so, copper has been the metal of the electrical age; so much so that the consumption of copper has come to reflect the level of material civilization. Where standards of living are high, so also is the rate of copper consumption.

Since 1900, world demand for copper has risen at a rate of about 4% per annum to reach a present day consumption of primary and secondary refined copper of around 8.5 million tons a year. The industry is however, undergoing far-reaching changes at the present time. Market conditions have, of late, been far from stable. Over the last decade or so, the price of copper has been on a continuous downward spiral and is currently near its lowest ever. Many industry analysts have attributed the low price to a prolonged slack in demand because of competitive pressures from substitute materials, especially aluminum. The copper content in the average room air-conditioner, for instance, dropped from 8.7 lbs. in 1970 to 6.0 lbs. in 1975, partly due to aluminum substitution and partly due to the adoption of thin walled tubing. Being extremely capital-intensive, the copper industry faces serious implications from low prices and substitution in terms of its future expansion and even sustenance.

The U.S. leads the world in both mine and refined production of copper with figures of approximately 18% and 20% of total world production, respectively. The U.S. is also the leader in consumption of refined copper, consuming approximately 26% of the world's refined copper. The U.S. net import balance is typically about 5 to 10% of total copper consumed in the U.S. in any year.

The aggregate demand for copper in the U.S. is thus an important component of aggregate world-wide demand. This report analyzes the demand for copper in the U.S. by dis-aggregating total demand according to its end-use applications. Thus, copper demand is categorized into five broad industrial sectors of the economy and analyzed within this sectorally disaggregated framework.

Such an approach is inspired by the fact that the entire industry is, in the final analysis, geared towards meeting the needs of the end-use sectors. The various end-users are collectively the prime-mover of the whole industry and the demands generated by each sector are critical determinants of the state of the domestic market in copper.

This report has the following objectives:

1. To formulate and estimate the structural relationships between copper consumption and its determinants in the major end-use consuming sectors.
2. To estimate the demand elasticities of price and economic activity in each end-use sector.
3. To determine the relative importance of other independent variables on the average annual changes in copper demand.
4. To use the estimated structural relationships to project the future demand for copper under different scenarios using the important exogenous variables.

Such an excercise, it is envisaged, will be useful to planners and decision makers in both the public and private sectors. In the short term, private sector planners need to analyze trends and prepare future demand scenarios for sales planning, purchasing and production, and assesments of future cash flows. Public sector requirements for demand analysis include applications for predicting future employment trends, planning for energy and other raw material requirements, and evaluating the effects of short-term government policies, such as price controls, on the domestic industry.

In the medium-term, forecasts and analysis of the demand for copper are used in the private sector for decisions related to the planning of productive capacity, procurement of raw materials, energy and labor, planning for capital requirements, and for market development. Public sector uses include inputs into the analysis of effects of longer-term government policies such as government funded R&D projects which may affect the demand for copper either through improving performance characteristics or reducing the costs of utilization.

Chapter II

OVERVIEW OF THE INDUSTRY AND THE DOMESTIC MARKET

2.1 THE INDUSTRY

Copper ore is mined from the earth using underground or open-pit mines. The ores are then concentrated by separating the valuable minerals from the worthless material. This process is known as milling. The next step is smelting, in which the sulfur in the ores is removed in the form of sulfur-dioxide. The smelted copper, known as 'blister' copper is then refined in refineries and sent to semi-fabricators (wire-mills, brass-mills, foundries, and powder-mills) where they are made into various shapes.

It is, therefore, the demand for semi-fabricated products that is relevant to this study. Semi-fabricators themselves do not make significant decisions about how much copper to use. Decisions on substitution are made by users of semi-fabricated copper products, presumably on the basis of a comparison between the prices of copper and the prices of substitute products. It is unnecessary, in fact unreasonable, to specify copper demand differently for refined copper, scrap, and alloy ingot as semi-fabricators can readily substitute one form of copper for another.

Copper is demanded by the final consumers (house-holds and individuals) not in the form of copper wire, plate or tube, but as an integral part of the goods they spend their income on. The focus of this report is the broad end-use industrial sectors in which copper is used to manufacture the goods that individuals and house-holds buy, and the demand for copper generated by such sectors. The demand functions estimated here would, therefore, be more appropriately termed 'derived demands'.

2.2 THE DOMESTIC MARKET

Eleven major firms dominate the U.S. primary copper production. Eight of these are fully integrated from mining through refining. Some are integrated right up to fabrication. Four firms account for approximately 70% of domestic refinery capacity, 80% of domestic smelter capacity, and 60% of mine output. Besides direct ownership, these firms exert control over the output of other mines via their control over smelting capacity and through partial ownership of smaller firms.

As a result of this high concentration, the domestic price of copper is not a free-market price. Thus, a two-price system has evolved wherein domestic copper in the U.S. moves at the U.S. producer price and most of the other copper moves at the London Metal Exchange (LME) price. The U.S. producer price is generally much less volatile than the competitive LME price. A detailed discussion of this two-price system can be obtained in [7]. For the purposes of this report, the brief discussion that ensues is sufficient.

The most plausible explanation for the two price-system is as follows: U.S. producers set the producer price at a sustainable and profitable long-run level of prices, based on the long-run total cost of production. Believing a stable price to be in their best long-run interests (given the possibility of encouraging entry and increased substitution), they take the price as given for the time being and decide on the amount of copper they will supply at that price. This determines the supply of primary copper in the U.S., net of imports.

In recent years, the U.S. producer price has been substantially below the LME price. The question that arises here is: Why does arbitrage not reduce the LME price and deplete U.S. stocks even though the LME-U.S. producer price differential is well above arbitrage costs (ocean-freight, insurance, and lighterage)? Fisher, Cootner and Baily [2] offer the view that in a situation where U.S. producers ration their sales at prices lower than LME prices, favored customers are unwilling to jeopardize their long-run relations with the producers for the sake of short-term gains from arbitrage. Presumably, U.S. producers can fairly readily discover if a large customer is re-selling on the LME. It appears that the major consumers also value the resulting price stability.

It is, therefore, postulated that in the short-term, exogenous influences shift the supply curve, not the demand curve; consequently, the amounts consumed by the different industrial sectors trace out the sectoral demand curves. This would also dictate the appropriate choice of price in the modelling employed in this report. The imperfectly competitive market thus makes possible an identification of the demand curve which would not be possible in a competitive market where simultaneous shifts in demand and supply would occur.

Domestic sales through marketing channels of the primary producers at the uniform producer price account for about 80% of annual consumption. The remaining consumption needs are met by :

(a) Custom refiners, for whom scrap is the major input. Their output typically sells at the competitive LME price.

(b) U.S. metal merchants, who hold or finance copper stocks but do not invest in production facilities.

(c) Imports.

The large quantity of copper traded at the U.S. producer price relative to all other copper traded, and the institutional arrangements between the major producers and industrial sector consumers, provide the justification for the selection of the U.S. producer price as the relevant price for subsequent analysis.

Chapter III

LITERATURE REVIEW

There are five major copper econometric models in the open literature: Arthur D. Little (ADL) model [1], Fisher et al. (FCB) model [2], Charles River Associates (CRA) model [3,4], Carol Taylor (CT) model [5], and the MIDAS-II model [6]. A brief description of each of the above models follows.

The ADL model was developed to evaluate the economic impact of environmental regulations on the copper industry for the U.S. Environmental Protection Agency. Its short-run market clearing module consists of thirteen simultaneous linear equations which simulate the assumed behavior of the domestic copper industry on an annual basis, the demand equation being aggregated.

The FCB model was motivated by the interest of the Chilean government in determining the behavior of the world copper market as a prerequisite to governmental planning. The model thus covers the international copper primary market more thoroughly than the U.S. market. Separate linear demand equations are estimated for the U.S., Europe, Japan, and the rest of the world. However, these equations also represent region-wise aggregate demand.

The CRA model concentrates equally on the international and U.S. primary markets. Demand equations are estimated for U.S., Europe, Canada, Japan and the rest of the world in aggregate form.

The above three models link copper demand to deflated copper and aluminum prices and the Federal Reserve Board Production Index. Additionally, the one year lagged fabricator stock is used in the ADL model, while inventory changes of durable goods for copper-users are used in the FCB and CRA models. The functional types for the relationships of the ADL, FCB and CRA models are reported as equations 2.1, 2.2, and 2.3 respectively. Variable descriptions are also given below. Note that e_i, b_i, and c_i are coefficients (i = 0,...,6).

$$X_1 = e_0 + e_1\left(\frac{X_0}{Y_3}\right) + e_2 Y_0 + e_3\left(\frac{Y_1}{Y_3}\right) + e_4\left(\frac{Y_2}{Y_3}\right) + e_5 X_1(-1) + e_6 X_2(-1) \qquad (2.1)$$

$$X_1 = b_0 + b_1\left(\frac{X_0(-1)}{Y_3(-1)}\right) + b_2\left(\frac{Y_2(-1)}{Y_3(-1)}\right) + b_3 Y_0 + b_4 Y_4 + b_5 Y_4(-1) + b_6 X_1(-1) \qquad (2.2)$$

$$X_1 = c_0 + c_1 X_1(-1) + c_2\left(\frac{X_0}{Y_3}\right) + c_3\left(\frac{Y_2}{Y_3}\right) + c_4 Y_0 + c_5 Y_4 + c_6 Y_4(-1) \qquad (2.3)$$

Variable Descriptions

X_0 = Engineering and Mining Journal (EMJ) price of copper

X_1 = quantity of copper demanded

X_2 = Fabricator stocks

Y_0 = Federal Reserve Board Index of manufacturing production (Source: Current Business Survey - CBS)

Y_1 = LME copper price (Source: American Bureau Of Metal Statistics - ABMS)

Y_2 = Price of scrap aluminum clippings (Source: American Metal Market - AMM)

Y_3 = wholesale price index of durable manufacturing (Source: CBS)

Y_4 = Change of inventories of durable goods (Source: CBS)

The CT model is a quarterly rather than an annual model and the demand equation is the following:

$$CRC = a_1 CRC(-1) + a_2 CDEM + a_3 DSTK(-1) + a_4 DP_{EMJ}(-4) + a_5 RSR(-4) + a_7 WDUMS + a_8 WD3$$

where

CRC = Consumption of refined copper by fabricators

CDEM = fixed investment + gross auto product - producer investment in automobiles (Source: CBS)

DSTK = SREP - SREP(-1) where

SREP = end of period stocks of refined copper at primary producing plants (Source: Mineral Industry Survey - Copper Production)

$DP_{EMJ} = (P_{EMJ})/WPI$ where

P_{EMJ} = Engineering and Mining Journal domestic refinery price of copper

WPI = Wholesale Price Index

$RSR = P_{RBS}/P_{CAS}$ where

P_{RBS} = Price of #1 composition (red brass) scrap. (Source: AMM)

P_{CAS} = Price of cast aluminum (crank cases) scrap.

$MDP_{EMJ} = DP_{EMJ} / \sum_{i=1}^{4} DP_{EMJ}(-i)$

WDUMS = DUMS x DRC where

DMS = dummy strike variable (-1 for each month of strike)

DRC = domestic refinery capacity

WD3 = D3 x ARC(-1) where

D3 = 3rd quarter seasonal dummy (D3 = 0 for 1st, 2nd, and 4th quarter; D3 = 1 for 3rd quarter)

ARC = refined copper consumption by fabricators

The MIDAS-II model developed by Hibbard, Soyster and Gates [6] employed a demand equation of the following functional form:

$$X_t = \beta K_t P_t^{-\alpha} + (1-\beta) X_{t-1}$$

where

P_t = Copper price at period t

X_t = Copper demand at period t

K_t = Constant (depending on exogenous assumptions concerning aluminum price and economic activity)

α = Long-run price elasticity

β = Parameter depending on short- and long-run price elasticity

An examination of the functional forms employed by all the above models indicates that none of them provides a detailed disaggregated picture. Thus, they are not useful in obtaining answers to questions such as:

(i) How does increased activity in construction affect the demand for copper?

(ii) Is the substitution of copper by aluminum more significant in some sectors of industry than in others?

(iii) What differential effects, if any, will government measures such as price controls have on the various copper-consuming sectors?

These and other questions can be answered with greater accuracy using an econometric model that expresses copper consumption in various sectors in terms of the exogenous variables affecting that particular sector. The rest of this report dwells on the construction of such a mathematical model.

Chapter IV

MODELLING STRATEGY AND METHODOLOGY

The existing copper econometric models [1,2,3,4,5,6] described in the previous chapter all employ aggregate copper demand functions. These models are not entirely satisfactory in one key instance: when the demand function for copper for one or more end-uses is nonlinear. Suppose, for example, that the demand functions for 2 end-uses are respectively the following:

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \quad \text{--------------} \quad (4.1)$$

$$y_2 = \beta_3 \, x_4^{\beta_4} \, x_5^{\beta_5} \quad \text{--------------} \quad (4.2)$$

The aggregate demand function would then be:

$$y = y_1 + y_2 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_4^{\beta_4} x_5^{\beta_5} \quad \text{------} \quad (4.3)$$

Estimation of equation (4.3) would require not only a nonlinear estimation techique but also a prior specification of the functional forms of equations (4.1) and (4.2). If a linear estimation technique were used directly to regress y on x_1, x_2, x_4, x_5, it would yield the following equation:

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_4 x_4 + \alpha_5 x_5 \quad \text{------} \quad (4.4)$$

This is clearly different from the 'true' aggregate demand which is expressed by equation (4.3).

Secondly, data limitations would preclude the use of more than a few variables in the regression to estimate equation (4.4). Inclusion of all price and activity variables that affect copper demand in each end-use sector would use up most, if not all, of the degrees of freedom.

Thirdly, the various industrial activity variables for estimating an aggregate copper demand function are highly collinear. Thus, inclusion of more than one activity variable would lead to multi-collinearity problems.

The procedure adopted in this report is to analyze the demand for copper in each end-use. By so doing, all the relevant variables are taken into account without encountering serious estimation difficulties. The total demand for copper is disaggregated into five distinct end-use sectors These sectors have been based on the classification listed by the Copper Development Association (CDA) in its annual report of copper industry statistics [8]. These five end-use sectors combine similar industries to facilitate econometric estimation.

A preliminary functional relationship of the demand for copper in any end-use sector may be written as follows:

$D_i(t) = f(EA_i(t), COPP(t), ALP(t), OTHER)$

where

$D_i(t)$ = Demand in end-use sector i in year t

$EA_i(t)$ = Economic activity in sector i in year t

COPP(t) = Average price of copper in year t

ALP(t) = Average price of aluminum (which is the principal substitute for copper) in year t

OTHER = Other variables affecting copper demand in sector i

Linear and logarithmic forms were investigated using the ordinary least squares methodology (OLS). The linear form assumes that the effect on copper demand of EA (t), COPP(t), ALP(t) and OTHER are additive, and that a given absolute change in any one variable has the same absolute effect on demand for all values of that variable. The logarithmic form makes the assumption that the effects of the exogenous variables are multiplicative and the elasticities of demand with respect to those variables are constant for all values. The linear forms were observed to yield better overall fit.

However, it was reasoned that the demands for copper in the various sectors are probably mutually related through their disturbances because each equation would contain some predetermined variables common with the other equations. The Seemingly Unrelated Regressions (SUR) technique proposed by Arnold Zeller [9,10] can, theoretically, be exploited to yeild more efficient estimators of the model coefficients.

Zellner showed that the SUR technique leads to asymptotically more efficient estimators than those obtained by OLS applied to each equation separately. Furthermore, the SUR estimator's variances are not far different from their asymptotic variances for a wide range of correlation coefficients between disturbances of the various sectoral equations.

Each of the five relationships estimated via OLS prior to using SUR satisfy all the standard OLS assumptions concerning the disturbance of each equation and uni-directional flow of causality from exogenous variables to a single endogenous variable. These equations also satisfy the SUR criterion that each equation has at least one predetermined variable that does not appear in any of the other equations, even though some predetermined variables may be common to each. The disturbance term of each equation represents the effects of all variables not explicitly included in the equation. The combined effects of a set of variables common to all equations thus leads to a nonzero correlation among the disturbances of the equations. In light of the above, SUR was retained as the most appropriate estimation technique in such a study. (In this particular report, the OLS procedure yeilded results very similar to SUR).

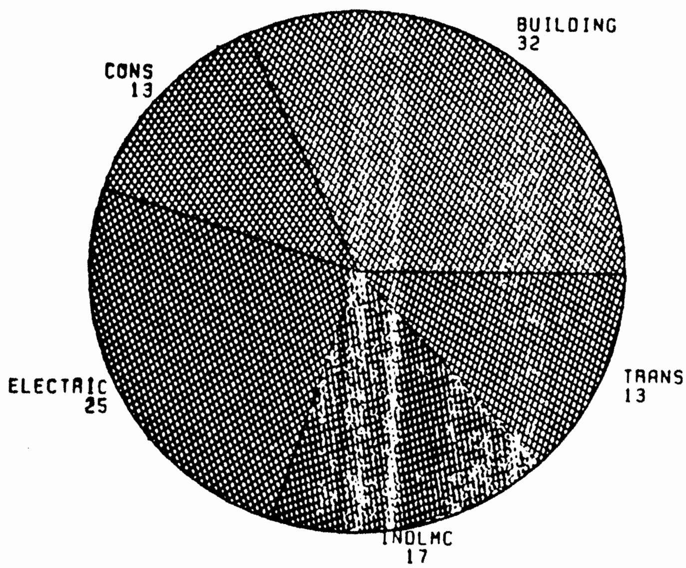
The end-use markets to which copper demand has been disaggregated for the purposes of this study are:

1. Electrical and Electronics
2. Industrial Machinery
3. Building and Construction
4. Transportation
5. Consumer Goods

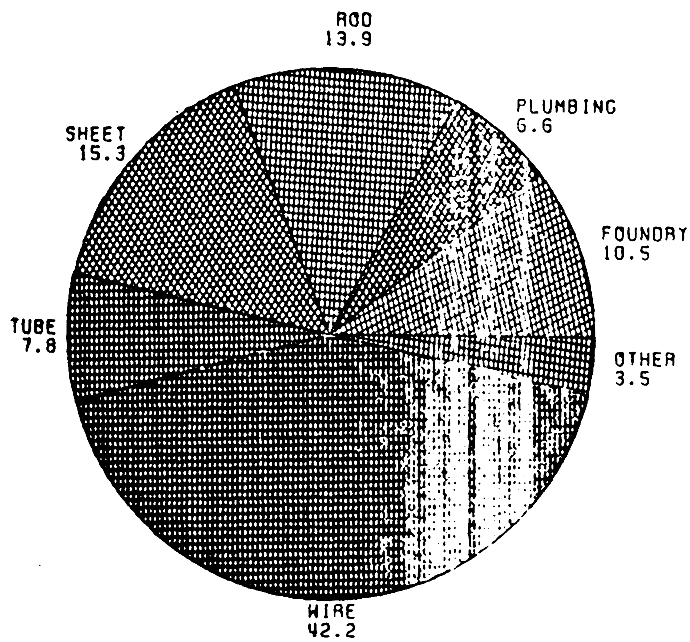
The average historical breakdown of copper consumption by end-use is given in Figure 1. In the end-uses shown, copper is used either directly or in alloys.

Figure 2 shows the various physical forms in which copper may be fabricated and a rough percentage breakdown by specific form.

CDA statistics [8] list the total metal weight of products going to the domestic market according to the five



BREAKDOWN OF COPPER CONSUMPTION
BY END-USE IN 1978
FIGURE 1



BREAK-DOWN OF COPPER CONSUMPTION
BY PHYSICAL FORM
FIGURE 2

end-uses mentioned earlier. From these, the weight of copper was computed on the basis of percentages furnished by the CDA in personal communications. A breakdown of end-uses and respective percentages are tabulated in Appendix A. A more detailed list of specific end-uses is presented in Appendix B. Average yearly U.S. producer prices for copper (ingot) and aluminum (electrolytic) were compiled from the American Metal Market newspaper and deflated to 1979 dollars. A complete description of the variables used is given in Chapter 5.

To capture the effect of substitution of copper by aluminum, some previous researchers have employed an independent variable that is the ratio of the copper price to aluminum price. Such a strategy, however, constrains the copper price and the reciprocal of the price of aluminum to have the same coefficient. Regressing them separately allows them to take on separate coefficients. The latter was, therefore, considered to be a superior alternative and employed in this report. Time series data for the most recent nine year period available (1970-78) were used in the estimation. (All data used in the estimation are given in Appendix C.)

Chapter V

RESULTS

The sectoral demand equations were estimated using the Seemingly Unrelated Regressions technique (mentioned in the previous chapter), subsequent to ordinary OLS estimation. This chapter presents both the OLS and SUR equations for each sector, and associated statistics.

The results to follow give the SUR equation followed by the OLS equation for each sector. Theory suggests negatively sloped price-quantity demand curves and positively sloped substitute price-quantity and activity-quantity curves (assuming absence of any correlation among independent variables). One would, therefore, anticipate a negative sign with the own-price coefficient and positive signs with the substitute price and activity variables. Given in parentheses below each coefficient value is its corresponding t-statistic. For the OLS equations, the R-square, (the multiple correlation coefficient), MSE (the mean square error), and DW (the Durbin-Watson statistic) are also listed. A brief review of the OLS and SUR procedures and the statistics reported here is presented in Appendix E. The elasticities with respect to the important variables are given in tables following the equations.

The following are the system statistics for the SUR results:

Weighted mean square error for the system = 1.704242

Weighted R-square for the system = 0.9783

This is the R-square that corresponds to the approximate F-test on all non-intercept parameters in the system.

The common variables in the equations are:

COPP: U.S. producer price for copper in 1979 U.S. dollars

ALP: U.S. producer price for aluminum in 1979 U.S. dollars

TIME: The year, e.g. 70, 71... for 1970, 1971...

Other variable descriptions appear along-side the equations.

The activity indices for the various sectors were obtained from "Statistical Abstract of the United States, 1981".

5.1 ELECTICAL AND ELECTRONICS SECTOR

SUR: ELECQ = 9893.784 - 8.0067COPP + 10.4155ALP +
(8.446) (-4.2184) (7.263)
17.4347EMACHX - 144.9488TIME
(13.5334) (-9.2439)

OLS: ELECQ = 10435.74 - 8.8457COPP + 11.2829ALP +
(8.2975) (-4.4373) (4.3925)
17.5903EMACHX - 152.0877TIME
(12.2038) (-8.7439)

R-square = 0.9755

MSE = 1139.602

DW = 2.4322

Variable Descriptions

EMACHX = Electrical Machinery Index (Base 1967 = 100)

ELECQ = Quantity of copper demanded in the Electrical and Electronics sector in millions of pounds

Elasticities with respect to the different independent variables were computed at the means and are listed in Table 1 on Page 26.

5.2 INDUSTRIAL MACHINERY SECTOR

SUR: INDLMCQ = 11303.92 (3.4844) - 8.7848COPP (-1.94) + 15,979INDLX (3.9548) - 156.896TIME (-3.5221)

OLS: INDLMCQ = 10615.94 (3.217) - 7.985COPP (-1.7445) + 15.0522INDLX (3.6387) - 147.0368TIME (-3.2382)

R-square = 0.774

MSE = 4625.9

DW = 1.6742

Variable Descriptions

INDLMCQ = Quantity of copper demanded in the Industrial Machinery sector in millions of pounds

INDLX = Index of Non-electrical Machinery (Base 1967 = 100)

TABLE 1

Elasticities at the Means: Electrical and Electronics Sector

Elasticity with respect to	OLS	SUR
COPP	-0.69	-0.62
ALP	0.49	0.45
EMACHX	1.86	1.84

Table 2 lists the elasticities for this sector computed at the means on Page 28.

5.3 BUILDING AND CONSTRUCTION SECTOR

$$\text{SUR:}\quad BUILDQ = \underset{(-2.4794)}{-1515.46} - \underset{(0.2505)}{0.4683COPP} + \underset{(2.0343)}{10.3176ALP} + \underset{(8.0029)}{13.3114BUILDX}$$

$$\text{OLS:}\quad BUILDQ = \underset{(-2.1810)}{-1442.78} - \underset{(-0.2753)}{0.5289COPP} + \underset{(1.7800)}{9.9935ALP} + \underset{(7.5204)}{13.0563BUILDX}$$

R-square = 0.928

MSE = 5297.548

DW = 2.0264

Variable Descriptions

BUILDQ = Quantity of copper demanded by the building and construction sector in millions of pounds

BUILDX = Value of new construction put in place in millions of 1979 dollars

Table 3 lists the elasticities of the variables computed at their means on Page 29.

TABLE 2

Elasticities at the Means: Industrial Machinery Sector

Elasticity with respect to	OLS	SUR
COPP	-0.86	-0.95
INDLX	2.16	2.29

TABLE 3

Elasticities at the Means: Building and Construction Sector

Elasticity with respect to	OLS	SUR
COPP	-0.032	-0.029
ALP	0.34	0.35
BUILDX	1.61	1.64

5.4 TRANSPORTATION SECTOR

SUR: TRANSQ = 455.0746 − 0.39588COPP + 7.9151TRANSX − 8.8495TIME

(0.3577) (−0.1678) (14.0378) (−0.5628)

OLS: TRANSQ = 293.4798 + 0.02660COPP + 8.3978TRANSX − 7.9304TIME

(0.2289) (0.0112) (4.2070) (−0.4999)

R-square = 0.8672

MSE = 2311.02

DW = 1.9958

Variable Descriptions

TRANSQ = Quantity of copper demanded by the transporation sector in millions of pounds

TRANSX = Transportation Equipment Index (Base 1967 = 100)

Table 4 lists the computed elasticities at the means for this sector on Page 31.

5.5 CONSUMER GOODS SECTOR

SUR: CONSQ = 5698.534 − 7.3198COPP + 6.1698DURX + 9.3616DURINV − 85.497TIME

(4.1641) (−2.5528) (3.8972) (2.5621) (−4.2431)

TABLE 4

Elasticities at the Means: Transportation Sector

Elasticity with respect to	OLS	SUR
COPP	0.004	-0.06
TRANSX	1.46	1.38

$$\text{OLS:} \quad CONSQ = \underset{(2.6837)}{5365.877} - \underset{(-1.4931)}{6.4166COPP} + \underset{(3.6525)}{6.3980DURX} + \underset{(1.2381)}{7.0820DURINV} - \underset{(-2.6050)}{78.386TIME}$$

R-square = 0.9064

MSE = 737.43

DW = 2.9407

Variable Descriptions

DURX = Index of durable manufactures (Base 1967 = 100)

DURINV = Inventory of durable goods in millions of 1979 dollars

Elasticities at the means for this sector have been computed and tabulated in Table 5 on Page 33.

TABLE 5

Elasticities at the Means: Consumer Goods Sector

Elasticity with respect to	OLS	SUR
COPP	-0.930	-1.060
DURX	1.145	1.104
DURINV	1.440	1.900

Chapter VI

FORECASTS

An important use with the model presented in the previous chapter is to forecast the demand for copper in the U.S., given specific assumptions about the future behavior of the exogenous variables. The individual equations follow the pattern of actual data well and catch all the major turning points. Thus, fairly accurate forecasts appear to be possible if reasonable estimates of future values of exogenous variables can be made. Since the near- and medium-term economic future is highly uncertain, three alternative assumptions have been made regarding the major economic activity variables. Forecasts have been made for all years till 1987; the structure of the demand for copper is not expected to change radically by then (relative to the past decade).

This chapter contains the forecasts of exogenous variables for each sector and also the picture of future copper demand that emerged thereby. Contrary to expectation, there was no evidence of autocorrelation in the various sectoral economic activity indices, or in the other exogenous variables forecast. Hence, base-case forecasts of exogenous variables were made using a linear time trend. Ninety-five percent confidence limits about the base-case were used to obtain high and low scenarios of the sectoral activity variables. For variables other than those of sectoral activity, the base-case trend was assumed. The estimated forecasting equations and related statistics are given in Appendix D. The forecasts for copper price and aluminum price are given in Table 6 on Page 36.

Forecasts of all the other variables are given along with the respective sector descriptions below. The figures quoted in the paragraph at the start of each sector description refer to the respective SUR model.

6.1 ELECTRICAL AND ELECTRONICS SECTOR

All the estimated coefficients for this sector, in both the SUR and OLS models are significant at the 5% level. The own-price elasticity is -0.69 and the cross-priced elasticity with aluminum is 0.49. It is quite elastic with respect to the activity variable (1.84). The signs of the coefficients were in accordance with the theoretical predictions. The base-case, high and low forecasts for the Electrical Machinery index are given in Table 7 on Page 37.

The resulting values of ELECQ under SUR and OLS are listed in Table 8 on Page 38.

TABLE 6

Forecasts of Copper and Aluminum Producer Prices

Year	COPP	ALP
1982	55.14	62.32
1983	49.96	63.38
1984	44.78	64.44
1985	39.60	65.50
1986	34.42	66.56
1987	29.42	67.62

TABLE 7

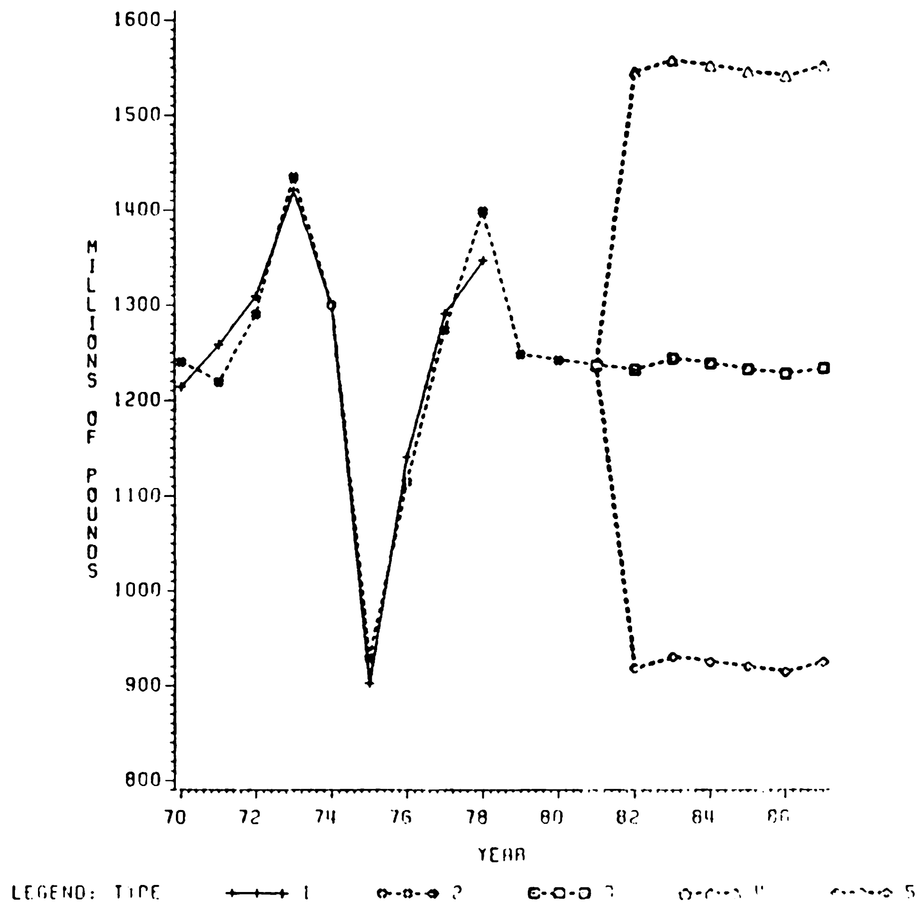
Forecast for EMACHX

Year	Base-case	High	Low
1982	173	191	155
1983	179	197	161
1984	184	202	166
1985	189	207	171
1986	194	212	176
1987	200	218	182

TABLE 8

Forecasts for ELECQ

Year	Base-case		High		Low	
	SUR	OLS	SUR	OLS	SUR	OLS
1982	1232	1223	1546	1557	918	906
1983	1244	1234	1558	1551	930	918
1984	1339	1228	1552	1544	925	911
1985	1233	1222	1547	1538	920	905
1986	1228	1215	1542	1532	914	899
1987	1238	1225	1553	1541	925	908



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE ELECTRICAL AND ELECTRONICS SECTOR
(PROCEDURE: SEEMINGLY UNRELATED REGRESSIONS)
FIGURE 3

Figure 3 is a graph of ELECQ vs. TIME showing actual, fitted, base-case forecasts and the forecasts with high and low sectoral activity scenarios using SUR.

Figure 4 is a graph of similar results obtained with OLS.

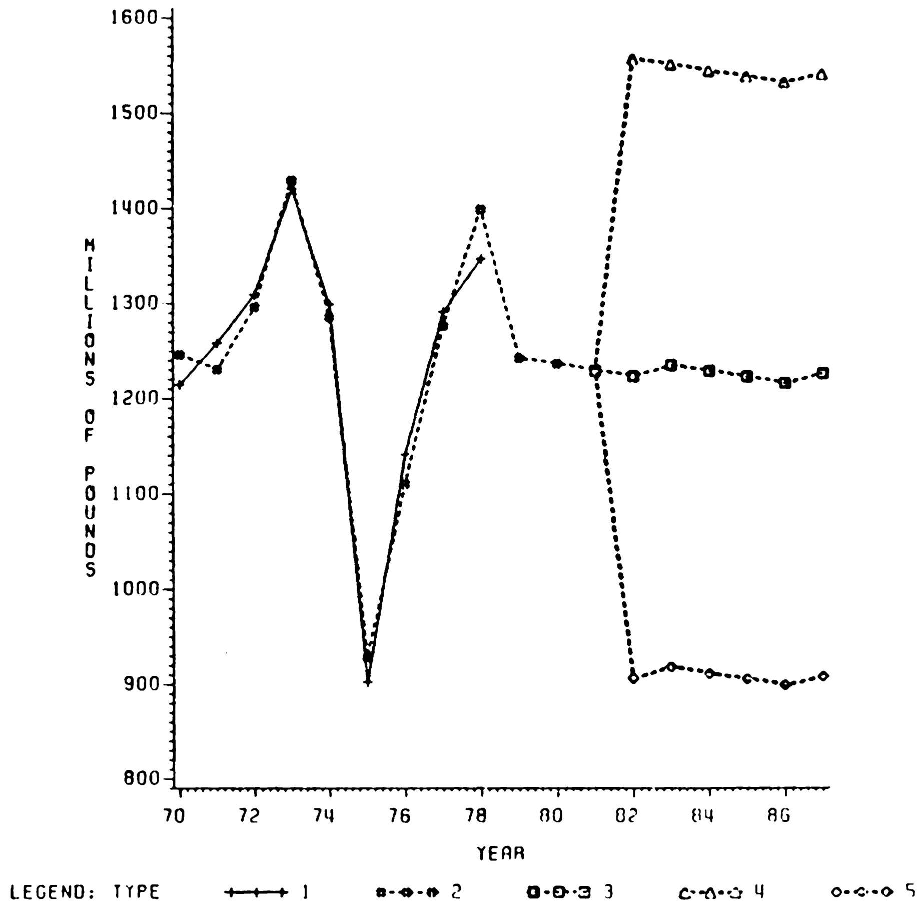
6.2 INDUSTRIAL MACHINERY SECTOR

All the variables in this sector except COPP were significant at 5%. The own-price elasticity was quite high (-0.95) and the activity elasticity was even higher (2.29). The aluminum price was found to be unimportant in this sector. All the coefficients were found to bear the "right" signs. The base-case, high, and low forecasts for the industrial activity index are given in Table 9 on Page 42.

The resulting values of INDLMCQ under both SUR and OLS are given in Table 10 on Page 43.

Figure 5 shows the actual, fitted, base-case, high, and low forecasts plotted against time using SUR.

Figure 6 shows a similar graph using OLS.



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE ELECTRICAL AND ELECTRONICS SECTOR
(PROCEDURE: ORDINARY LEAST SQUARES)
FIGURE 4

TABLE 9

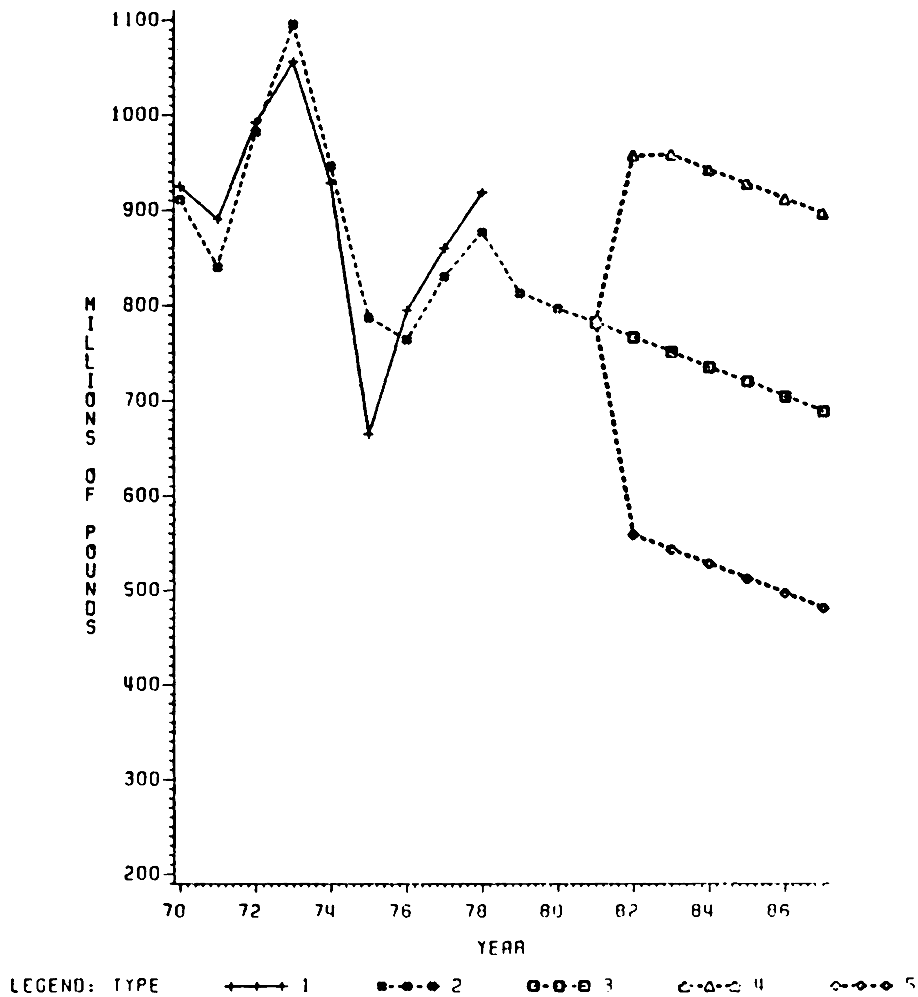
Forecasts for INDLX

Year	Base-case	High	Low
1982	176	188	163
1983	182	195	169
1984	188	201	175
1985	194	207	181
1986	200	213	187
1987	206	219	193

TABLE 10

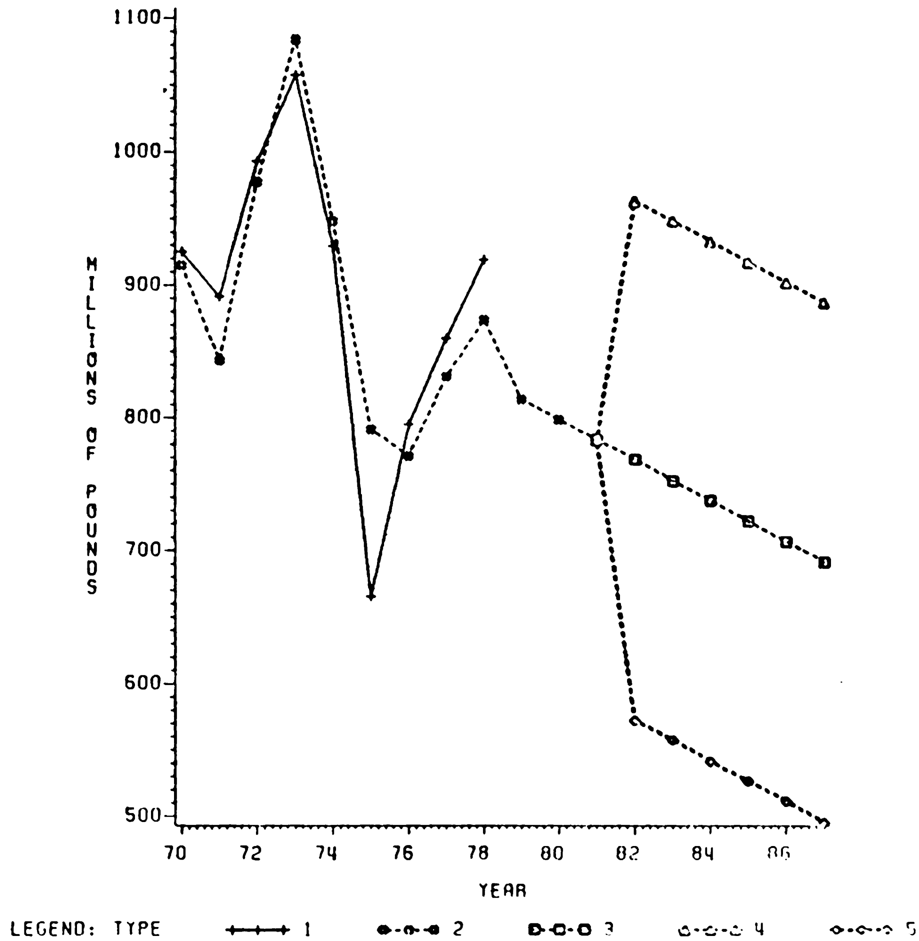
Forecasts for INDLMCQ

Year	Base-case		High		Low	
	SUR	OLS	SUR	OLS	SUR	OLS
1982	766	768	958	963	559	572
1983	751	752	959	948	543	557
1984	735	737	943	933	528	541
1985	720	722	927	917	512	526
1986	704	706	912	902	497	511
1987	689	691	897	887	481	495



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE INDUSTRIAL MACHINERY SECTOR
(PROCEDURE: SEEMINGLY UNRELATED REGRESSIONS)
FIGURE 5



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE INDUSTRIAL MACHINERY SECTOR
(PROCEDURE: ORDINARY LEAST SQUARES)
FIGURE 6

6.3 BUILDING AND CONSTRUCTION SECTOR

Only BUILDX was significant at 5% in this sector; in fact, it was even significant at 1%. BUILDQ is virtually entirely inelastic with respect to own-price and has a low cross-price elasticity with respect to aluminum (0.35). As expected, it is quite elastic with respect to BUILDX (1.64). The coefficients have signs in conformity with theoretical predictions.

In this sector, unlike the others, no time trend was discernible for BUILDX and so, the mean was used for the base-case forecasts for all future years without separate high and low activity scenarios. This mean was computed to be 193.56 and the resulting forecasts for BUILDQ are tabulated in Table 11 on Page 47.

Figure 7 shows plots of the actual, fitted, and forecast values against time using SUR.

Figure 8 shows similar plots for OLS.

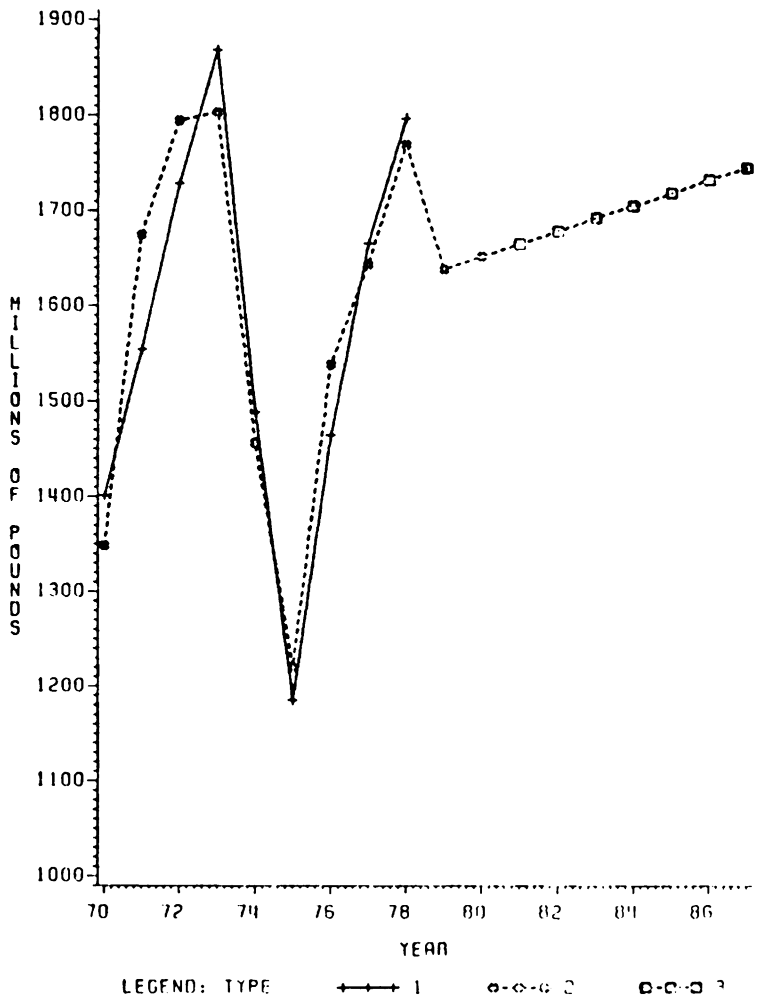
6.4 TRANSPORATION SECTOR

Only TRANSX was significant at 5% in the transporation sector; it was significant at one percent as well. Even

TABLE 11

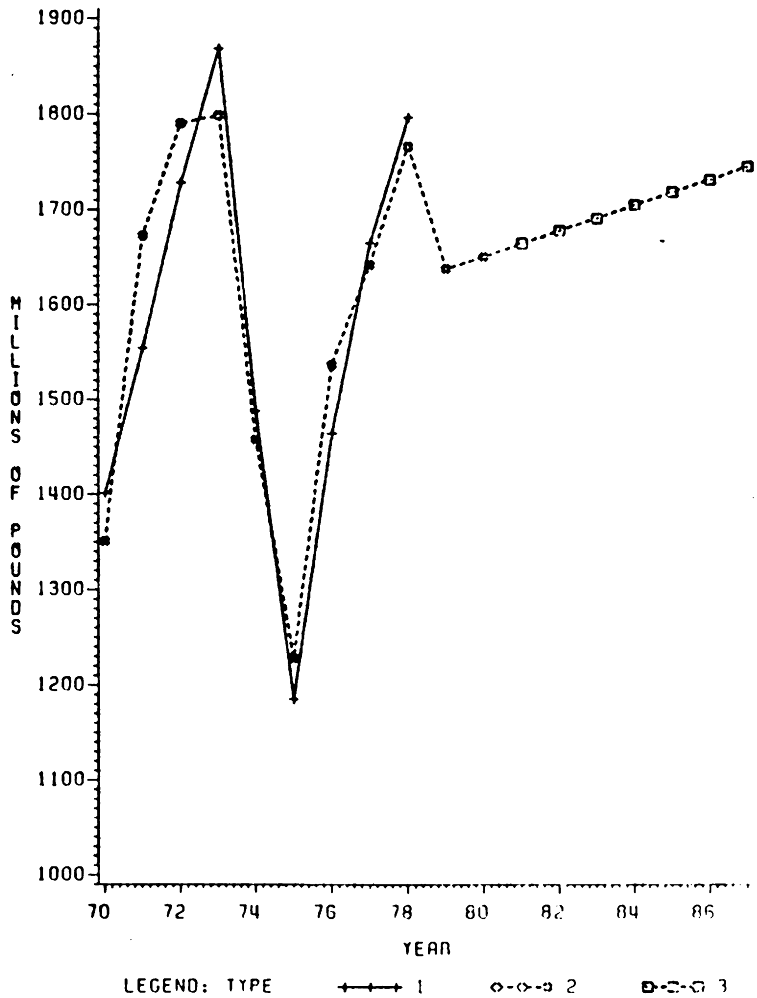
Forecasts for BUILDQ

Year	Base-case	
	SUR	OLS
1982	1678	1678
1983	1692	1691
1984	1705	1705
1985	1718	1718
1986	1732	1731
1987	1745	1745



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE BUILDING AND CONSTRUCTION SECTOR
(PROCEDURE: SEEMINGLY UNRELATED REGRESSIONS)
FIGURE 7



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECCAST

DEMAND FOR COPPER
IN THE BUILDING AND CONSTRUCTION SECTOR
(PROCEDURE: ORDINARY LEAST SQUARES)
FIGURE 8

though estimation under SUR yielded a negative sign for the coefficient for COPP, it was own-price inelastic. It was considerably elastic with respect to the transporation index (1.38). The signs of the coefficients were as expected. The base-case, high, and low forecasts for the Transportation index are given in Table 12 on Page 51.

The resulting values of TRANSQ under both the SUR and OLS procedures are tabulated in Table 13 on Page 52.

The actual, fitted, base-case, high, and low forecasts are plotted against time in Figure 9 using SUR.

Figure 10 is a similar plot using OLS.

6.5 CONSUMER GOODS SECTOR

All variables except COPP and DURINV were significant at the 5% level. The own-price elasticity was found to be very high in this sector (1.06). Copper demanded in this sector was found to be quite elastic with respect to DURX and DURINV also (the respective elasticities being 1.1 and 1.9). Coefficients for COPP, DURX, and TIME are in accordance with expectations. There could, however, be a question about the positive sign for DURINV. It might be argued, for instance, that as inventories of durable goods rise, copper demand should come down. This conclusion

TABLE 12

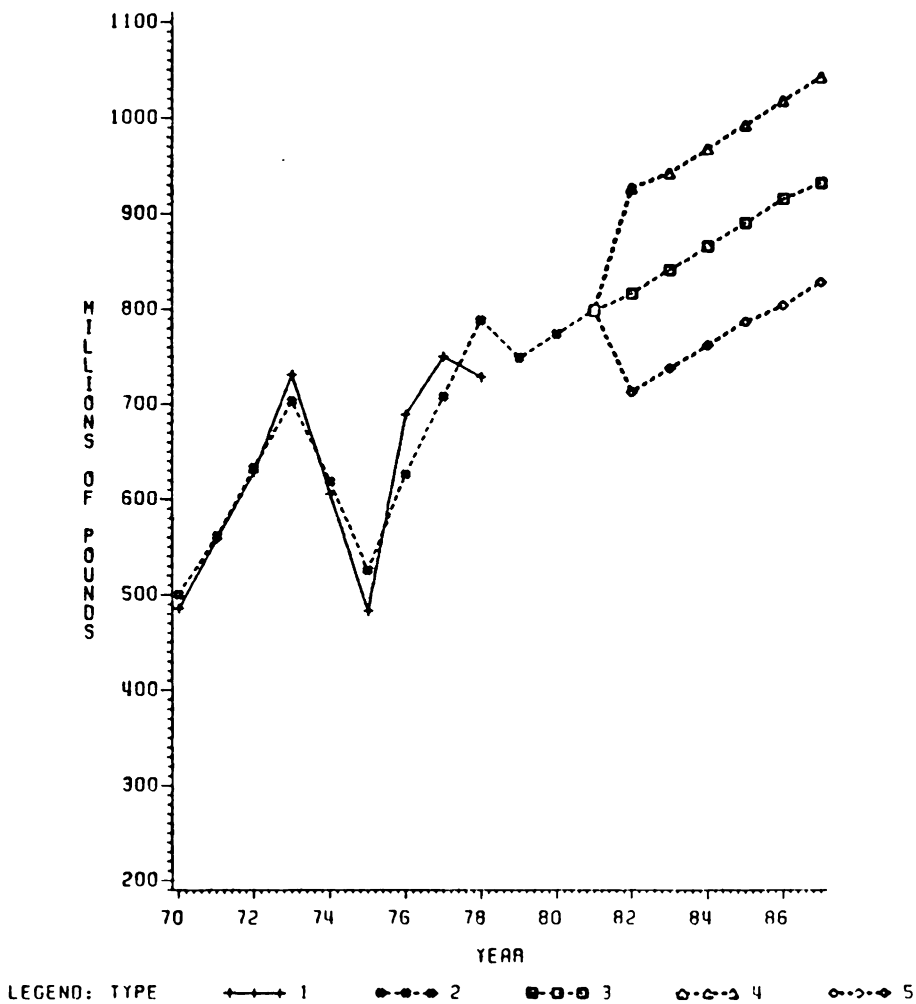
Forecasts for TRANSX

Year	Base-case	High	Low
1982	140	154	127
1983	144	157	131
1984	148	161	145
1985	152	165	139
1986	156	169	142
1987	159	173	146

TABLE 13

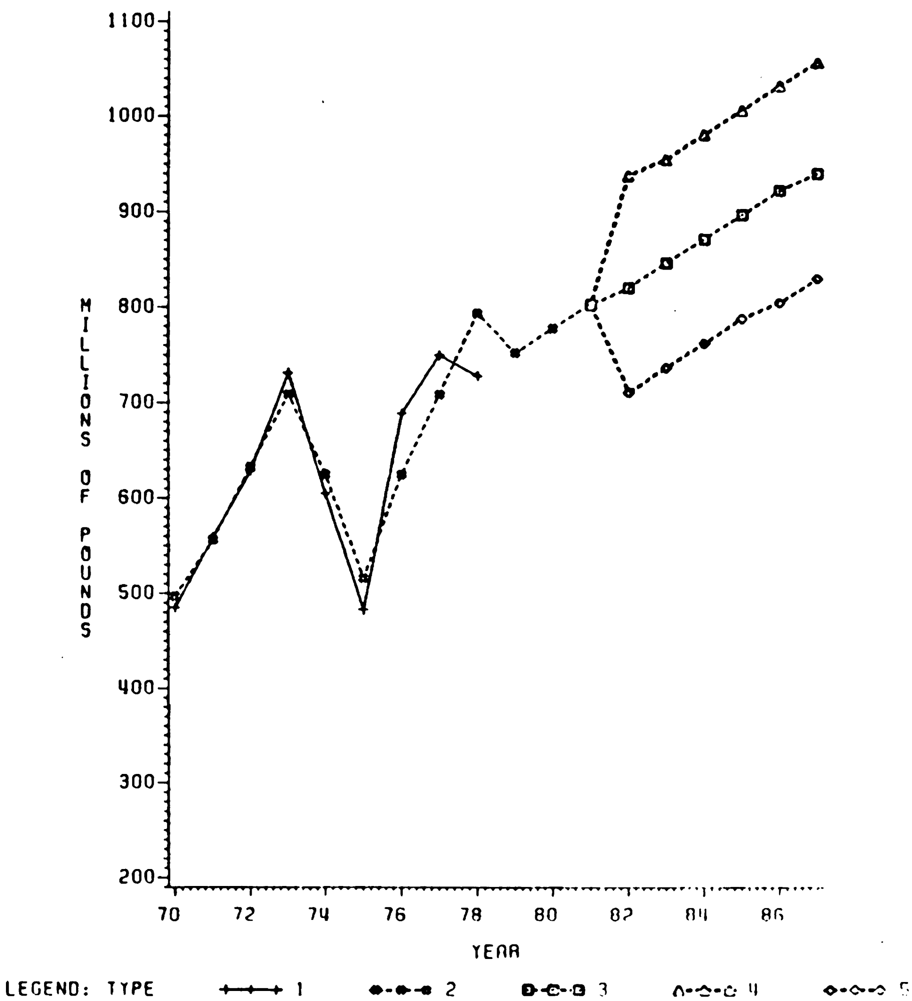
Forecasts for TRANSQ

Year	Base-case		High		Low	
	SUR	OLS	SUR	OLS	SUR	OLS
1982	816	820	926	938	713	711
1983	840	846	943	955	738	737
1984	865	871	968	981	762	762
1985	890	897	993	1006	787	788
1986	915	922	1018	1032	804	805
1987	932	939	1043	1057	829	830



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE TRANSPORTATION SECTOR
(PROCEDURE: SEEMINGLY UNRELATED REGRESSIONS)
FIGURE 9



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE TRANSPORTATION SECTOR
(PROCEDURE: ORDINARY LEAST SQUARES)
FIGURE 10

assumes that durable goods inventories grow when market demand for them is down; suggesting that if the durable goods do not sell, then semi-fabricators would demand less copper. However, these assumptions are far from obvious. One way to interpret the positive sign, without any assumptions on the link between inventories and market demand, is by asserting that with the production of durable goods increasing (irrespective of whether they are stored or sold), the copper demanded for use in their manufacture also increases.

The base-case, high, and low forecasts for the durable goods index are given in Table 14 on Page 56.

The resulting values of CONSQ under the SUR and OLS procedures are given in Table 15

The actual, fitted, base-case, and forecast high and low values are plotted in Figure 11 using SUR.

Figure 12 shows similar plots for OLS.

6.6 AGGREGRATE DEMAND

A weighted average of all the sectoral price-elasticities can be computed to express the elasticity of total copper demanded with respect to its own price.Using the shares

TABLE 14

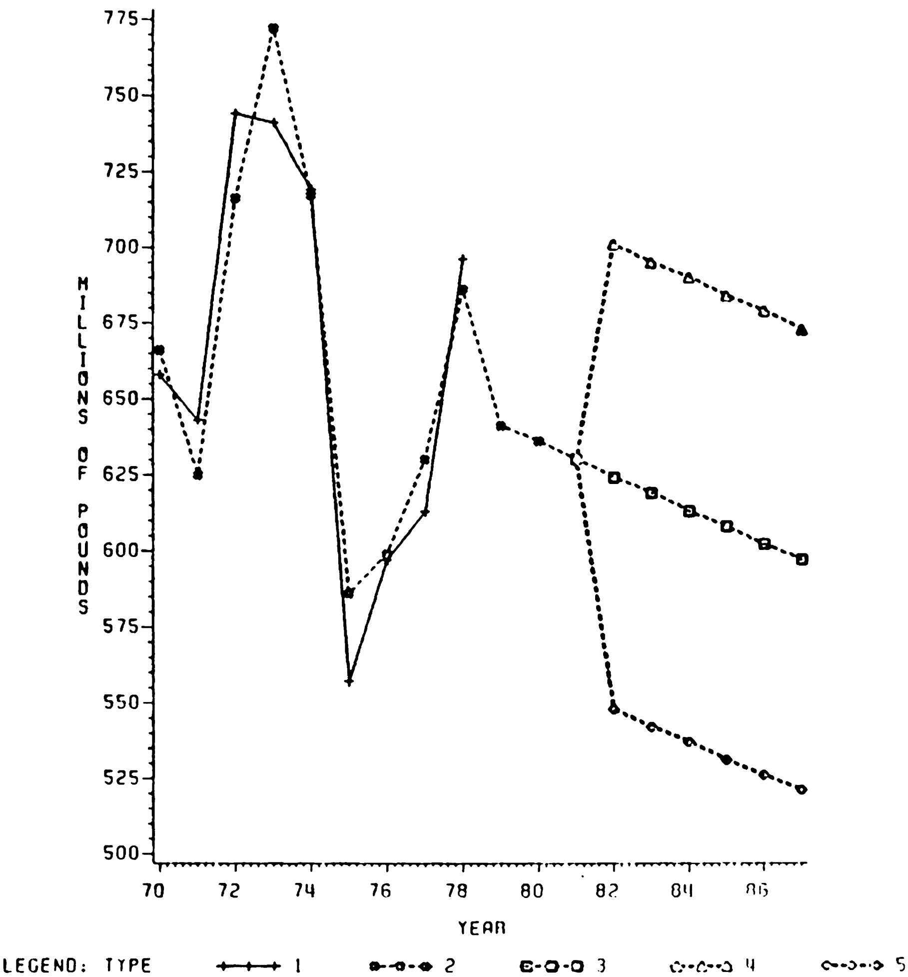
Forecasts for DURX

Year	Base-case	High	Low
1982	151	163	138
1983	155	167	142
1984	159	171	146
1985	162	175	150
1986	166	179	154
1987	170	183	158

TABLE 15

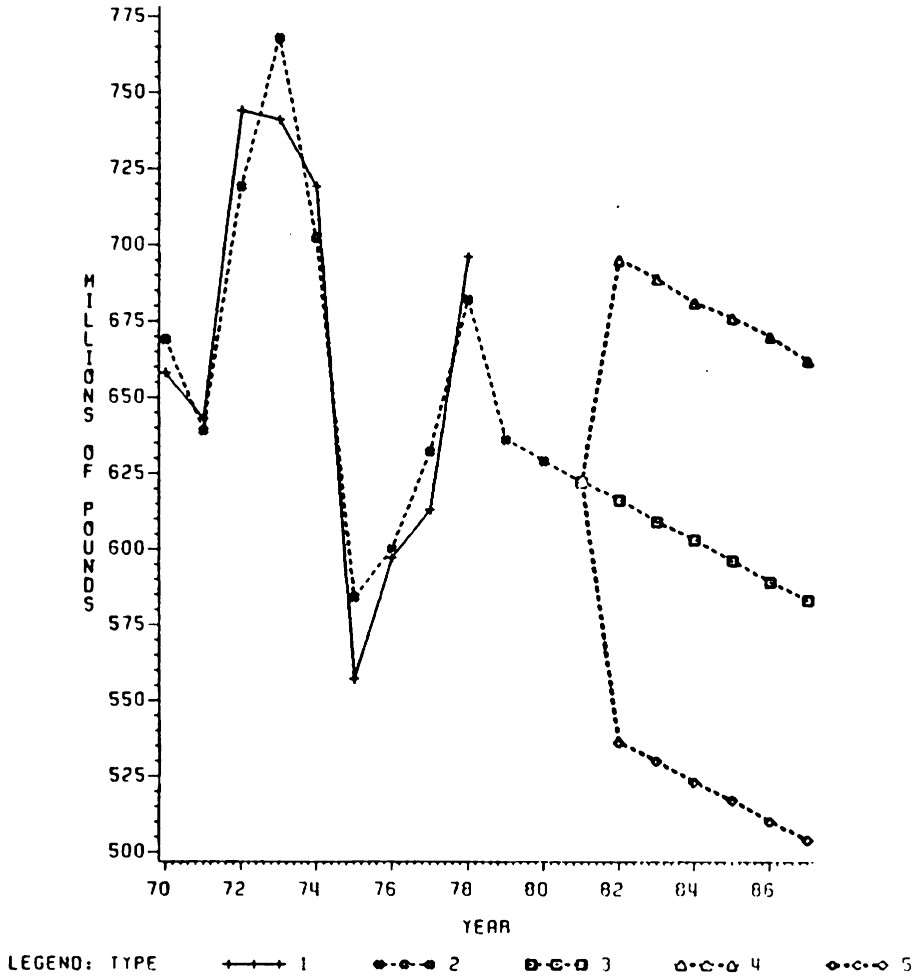
Forecasts for CONSQ

Year	Base-case		High		Low	
	SUR	OLS	SUR	OLS	SUR	OLS
1982	624	616	701	695	548	536
1983	619	609	695	689	542	530
1984	613	603	690	681	537	523
1985	608	596	684	676	531	517
1986	602	589	679	670	526	510
1987	597	583	673	662	521	504



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE CONSUMER GOODS SECTOR
(PROCEDURE: SEEMINGLY UNRELATED REGRESSIONS)
FIGURE 11



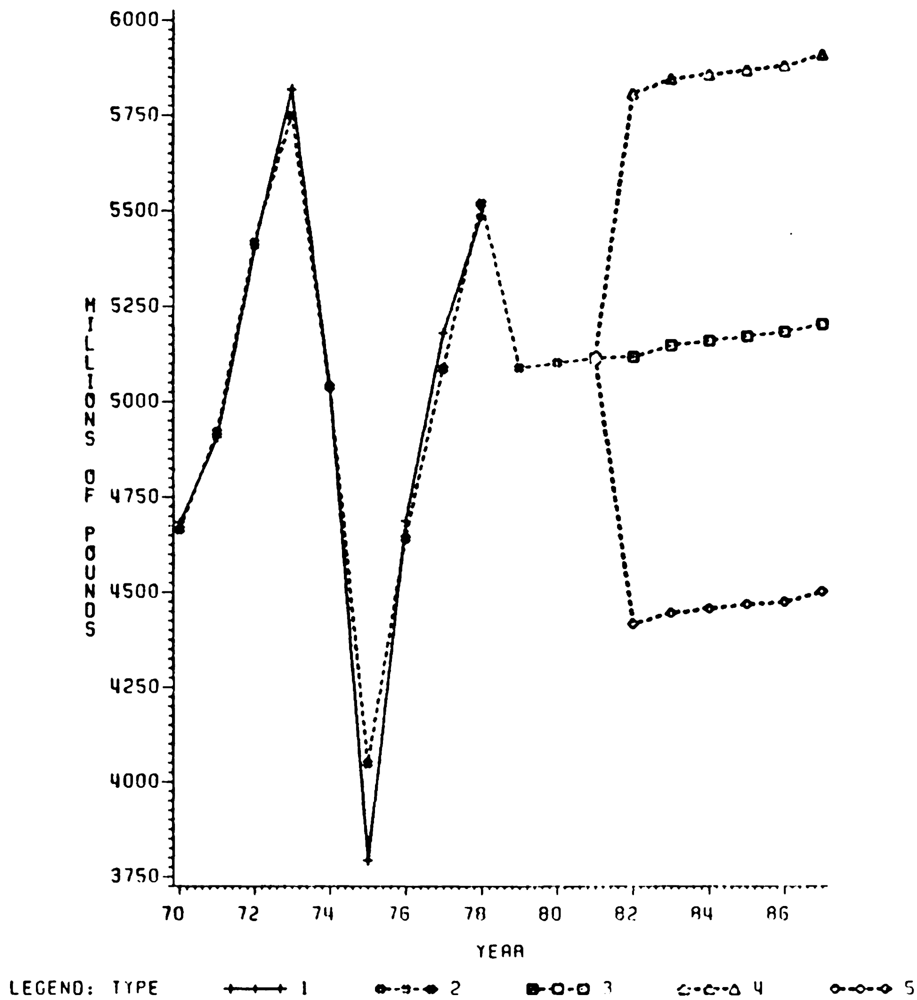
1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

DEMAND FOR COPPER
IN THE CONSUMER GOODS SECTOR
(PROCEDURE: ORDINARY LEAST SQUARES)
FIGURE 12

of each end-use of the total 1978 consumption as weights, an elasticity of -0.469 is obtained. It should be noted that such a weighted average of elasticities provides only a minimum estimate of the aggregate demand elasticity for it is almost impossible to measure the technological change induced by price changes. Such technological change is likely to be extremely infrequent, very long-run in nature, and irreversible.

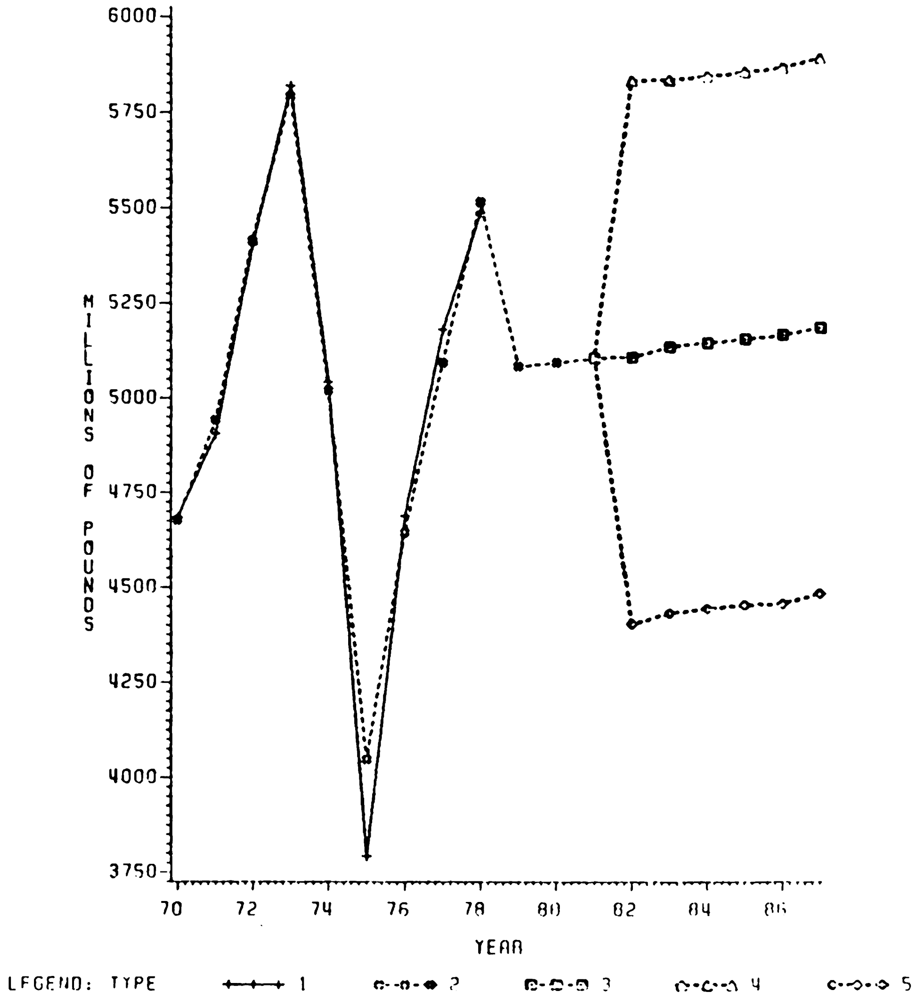
Figure 13 shows a plot of the actual, fitted, base-case, high, and low forecasts for the aggregate demand for copper using SUR.

Figure 14 shows a similar graph using OLS.



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECAST 4 HIGH FORECAST
5 LOW FORECAST

TOTAL DEMAND FOR COPPER
IN THE U.S.
(PROCEDURE: SEEMINGLY UNRELATED REGRESSIONS)
FIGURE 13



1 ACTUAL VALUES 2 FITTED VALUES
3 BASE CASE FORECCAST 4 HIGH FORECAST
5 LOW FORECAST

TOTAL DEMAND FOR COPPER
IN THE U.S.
(PROCEDURE: ORDINARY LEAST SQUARES)
FIGURE 14

Chapter VII

CONCLUSIONS

The quantitative results and forecasts obtained in the previous two chapters are supplemented by some qualitative observations and conslusions in this final chapter.

The medium-term outlook for the electrical and electronics industry is quite mixed. Investment in electrical generation and transmission is tapering off. Both the poor financial conditions of the utility companies and uncertainties about long-run demand contribute to this. As with heavy electrical equipment so also with the market for switchgear, motors, generators and transformers, the picture does not appear to be too bright. The near-saturation in the market for domestic telephones has closed off much of the telecommunications market to copper, too. The anticipated boom in communications systems is not expected anytime soon, and even if it does come, the equipment used does not tend to be intensive in their use of copper. High economic activity in the electrical and electronic sector (as in 1974) may shoot up the quantity demanded to almost 1550 million pounds and a slump (as in 1975) may drop it to as low as 900 million pounds; otherwise, it is expected to be around the 1250 figure.

Markets that have traditionally gone to copper are increasingly being penetrated by aluminum. Overhead transmission lines and underground power cables are two examples. A reduction in unit requirements for copper is also likely to result from the increased use of microwave transmissions. In telecommunications, new technological advances such as the wave guide system, optic fibers, and laser beams offer considerable savings over copper by greatly increasing the volume of messages that can be sent through a vehicle of diameter size similar to the copper telephone wire.

Copper use in the industrial machinery and equipment sector exhibits a downward trend. In the long-term, valves, bearings, and heat exchangers are all vulnerable to substitution by stainless steel or aluminum. Copper's tubing applications are also threatened in the long-run by steel and titanium. A potential new use for copper, however, is in desalination plants. A high of 980 million pounds and a low of 490 million pounds can be expected for copper demanded in this sector in the next five years with the base-case figure declining gradually.

The building and construction sector is a very important market for copper particularly in the form of brass alloys, and one in which it holds a fairly strong position. Copper is widely used in new construction and is even more preferred in the maintenance of existing buildings. Hot-water cylinders, fastenings, taps, valve-bodies, locks, and wall-cladding will continue to use copper with only marginal substitution. Substitution is also expected in plumbing and guttering tubes by PVC. Building activity is expected to have more or less the same levels as in the past and copper demanded in this sector is expected to be around 1725 million pounds by 1987.

The car industry has two important markets: wiring and radiators. Steel fins in radiators, and aluminum windings in dynamos and starter motors are, however, increasingly expected to threaten copper demanded in this industry, not to mention the highly fluid state of the automobile industry in general. The introduction of electric cars, whenever it comes, is expected to give a boost to copper demand. Shipbuilding, where copper is extensively used for propellers and steam turbines, will also use more copper over the long-run. Railways have been steady consumers of copper, too, though not much growth is expected in it. A record high of 1050 million pounds and a low of 700 are forecast for the next five years with base-case consumption rising from 800 to 950 million pounds.

The consumer goods sector exhibits virtually complete market saturation. Washing machines, radios, and TV sets are universally owned and the only demand is expected to be replacement demand. Copper use in this sector is, therefore, expected to decline in general. Even a high growth scenario does not match the 1974 peak level whereas low growth may plunge demand to as low as 515 million pounds. The base-case exhibits a gradually declining trend.

The above review suggests that the possibility of reduced copper demand increases with time, for, copper is not only subject to physical substitution (owing to the substitutes' lower prices) but also quantitative substitution (reduction of copper per unit of output) and invisible substitution (that is, when a new product is put on the market and although copper could have been used it uses a rival material). Sometimes, all three types of substitution occur in the same end product e.g., in automobile radiators. Thus, the longer the projection period, the more guarded the outlook must be. The dilemma facing copper producers can be summed up as follows: low copper prices mean low profits but high prices are likely to induce substitution to cheaper materials.

The quantitative analysis carried out in this report has, hopefully, shed some light on the future prospects for copper demand in its various end-use industries. However, as this chapter has made abundantly clear, not all factors affecting substitution and growth are quantifiable and the findings reported here will serve their purpose best if tempered with sound judgment.

Appendix A

COPPER AS A PERCENTAGE OF METAL WEIGHT IN SUPPLY TO END-USERS

Building and Construction Average	85.75
Plumbing and Heating	85.00
Air Conditioning and Commercial Refrigeration	98.00
Builders' Hardware	68.00
Architectural	92.00
Transportation Average	82.50
Automotive Nonelectrical	80.00
Automotive Electrical	70.00
Railroad	95.00
Marine	85.00
Consumer Goods Average	74.80
Coinage	93.00
Consumer Electronics	75.00
Appliances	70.00
Military and Commercial Ordinance	73.00
Fasteners and Closures	68.00
Utensils and Cutlery	70.00
Industrial Machinery and Equipment Average	75.60
In-plant Equipment	80.00
Industrial Valves and Fittings	62.00
Heat Exchangers	88.00
Non-Electrical Instruments	70.00
Off-Highway Vehicles	78.00
Electrical & Electronic Products Average	78.75
Telecommunications	70.00
Power Utilities	90.00
Lighting and Wiring Devices	80.00
Electronics (except Consumer Electronics)	75.00

Appendix B

DETAILED LIST OF END-USES FOR COPPER

Industrial Machinery and Equipment
Valves and Fittings
Chemical and Engineering Plant
Bronze Powders
Copper Salts
Refrigeration and Air Conditioning Plant
Friction Bearings
Electrical Power Station
Pumps
Machine Tools and Other Industrial Process Equipment
Oxy-acetelene Welding Equipment
Stationary Internal Combustion Engines
Foundrinier Wire
Small Arms and Sporting Ammunition
Brewery Plant
Food Processing Plant
Petrol and Oil Refinery Plant
Anti-friction Bearings
Rolling Mill Plant
Water Desalination Plant

Electrical and Electronic Products
Wiring Wires
Power Cables
Winding Wires
Telecommunication Cables
Other Cables
Motors and Generators
Switchgear and Bus Bars
Transformers
Wiring Accessories
Telecommunication Equipment
Lamp Caps

Building and Construction
Plumbers' Fittings and Brassware
Domestic Service Tubes
Water Heaters
Roofing
Fastenings
Locks and Furniture Fittings
Wall Cladding (external)
Metal Sections (windows, frames, etc.)
Art and Bell Castings
Foil for Ground Waterproofing

Gutterings and Drain Pipes
Lightning Conductors

Consumer Goods
Washing Machines
Refrigerators
Cutlery
Radio, TV Sets, Sound Equipment
Vaccuum Cleaners
Buttons and Buckles

Rail Transportation
Radiators
Cables Harnesses
Trim
Starter Motors
Car Heaters

Ship Building
Propellers
Marine Condenser and Associated Equipment
Electric Equipment
Sea Water Trunking
Deck Fittings
Valves
Sprinklers

Railways Electrification
Transformers
Cables
Electric Motors
Cooling Systems

Appendix C

DATA USED IN THE ESTIMATION

COPP	ALP	TIME	TRANSQ	TRANSX	ELECQ	EMACHX
122	56.4	70	485	90	1214	108
105	55.1	71	559	98	1258	108
100	48.6	72	628	108	1309	122
102	42.8	73	731	118	1420	143
112	49.8	74	605	109	1299	144
85	52.5	75	483	97	902	117
88	56.6	76	689	111	1141	135
79	62.0	77	750	122	1291	145
74	60.6	78	733	133	1374	159

INDLMCQ	INDLX	DURX	DURINV	BUILDQ	CONSQ	BUILDX
925	104	102	130	1401	658	176
891	100	102	121	1554	643	200
993	116	114	128	1728	744	214
1057	134	127	137	1868	741	220
929	140	126	148	1488	719	189
665	125	109	133	1185	577	168
795	135	122	138	1464	597	181
860	144	130	138	1665	613	192
919	154	140	142	1794	696	202

Appendix D

EQUATIONS USED TO FORECAST EXOGENOUS VARIABLES

$$TRANSX = \underset{(-1.99)}{-172} + \underset{(3.25)}{3.81}TIME$$

R-square = 0.60

$$EMACHX = \underset{(-2.26)}{-257} + \underset{(3.42)}{5.25}TIME$$

R-square = 0.62

$$INDLX = \underset{(-3.92)}{-317} + \underset{(5.56)}{6.01}TIME$$

R-square = 0.81

$$DURX = \underset{(-2.15)}{-169} + \underset{(3.67)}{3.90}TIME$$

R-square = 0.65

$$BUILDX = \underset{(1.37)}{240} - \underset{(-0.27)}{0.63}TIME$$

R-square = 0.01

$$COPP = \underset{(6.56)}{479.9} - \underset{(-5.25)}{5.18}TIME$$

R-square = 0.79

$$ALP = \underset{(-0.45)}{-24.6} + \underset{(1.45)}{1.06}TIME$$

R-square = 0.22

$$DURINV = \underset{(-0.11)}{-6.83} + \underset{(2.29)}{1.92}TIME$$

R-square = 0.43

Appendix E

BRIEF REVIEW OF OLS AND SUR PROCEDURES AND STATISTICS REPORTED

OLS Procedure:

The Ordinary Least Squares (OLS) procedure is the most common method to estimate the coefficients of a linear statistical model. The method involves fitting a hyperplane to the observations in such a way that the sum of squares of the residuals is a minimum. OLS estimators possess the least variance in the class of linear unbiased estimators.

If $y = X\beta + \epsilon$ is the true model and $Y = Xb + e$ the estimating model, then under a set of asumptions it is well known that by minimizing $(Y - Xb)'(Y - Xb)$ the estimator $b = (X'X)^{-1}X'Y$ is obtained. The assumptions and derivation can be found in any standard econometrics text.

SUR Procedure:

The Seemingly Unrelated Regressions (SUR) procedure estimates coefficients of a set of linear regression equations that are related through their disturbances. It yields estimatiors more efficient than those obtained by applying OLS to each equation separately.

Example: Let (1) and (2) below be two equations that are mutually related through their disturbances.

$$Y_1 = X_1\beta_1 + u_1 \text{ — — — — — — (1)}$$
$$Y_2 = X_2\beta_2 + u_2 \text{ — — — — — — (2)}$$

Assuming the OLS assumptions hold for each of the above equations, OLS yields estimators

$$\hat{\beta}_1 = (X_1'X_1)^{-1}X_1'Y_1$$
$$\hat{\beta}_2 = (X_2'X_2)^{-1}X_2'Y_2$$

(1) and (2) may be combined and written as

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

and abbreviated as $Y = X\beta + u$.

Let the estimating model now be $Y = Xb + e$.

Let the variance-covariance matrix of the error terms be

$$\begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix}$$

and let

$$\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix} \otimes I$$

where $\otimes$ is the Kronecker Product.

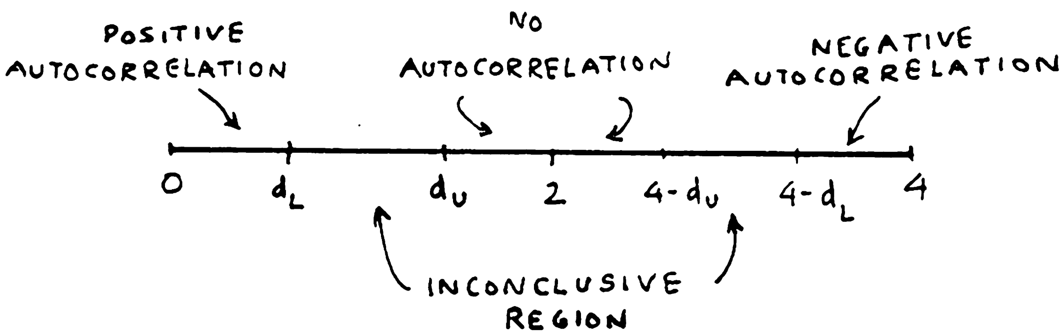
SUR then minimizes $(Y-bX)'\Sigma^{-1}(Y-bX)$, which is different from the quadratic form minimized in OLS. The resulting estimator is $b = (X'\Sigma^{-1}X)^{-1}X'\Sigma^{-1}Y$,

where $b = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$

MSE: Mean Squared Error is the mean of the squared residuals e_i i.e. $MSE = \frac{\sum_{i=1}^{n} e_i^2}{n}$

R-Square: R-square is the proportion of the total variance that is explained by the model.

DW: The Durbin-Watson is a statistic to test for first order autocorrelation. DW statistics tables may be found in any standard econometrics text. The DW lies in the interval [0,4] and an inference on autocorrelation is drawn depending on where on the interval lies the DW statistic in question. The representation below will make this clearer.



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