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An econometric model of the world cobalt industry

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Kieler Arbeitspapiere

Kiel Working Papers

Working Paper No. 129

An Econometric Model of
the World Cobalt Industry

by
Poonam [Gupta⁺

November 1981

Institut für Weltwirtschaft an der Universität Kiel

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I INTRODUCTION AND NATURE OF THE COBALT MARKET

This study presents an econometric model of the world cobalt industry, relatively disaggregated to incorporate different demand equations for the United States, and rest of the non-communist world, as well as a breakdown into types of cobalt used. Largely due to reasons of data availability, the model is an annual one and the breakdown by end use categories has been restricted to the United States. Particular attention in the model construction has been given to price setting in the cobalt market. Existing evidence by Burrows (1971) and Charles River Associates (1976) suggests that Zaire sets the price so as to maximise its own profits.

The aim of this study is to estimate aggregate and disaggregate short run and long run elasticities with respect to price and activity variables, and to test whether the own profit maximization hypotheses is representative of current producer price setting behaviour when Zaire's share in total world mine production has fallen from nearly two thirds to less than half between 1972 and 1978. Finally, the model constructed is used to simulate the effect of marginal cost pricing by major producers and the movements in price resulting from an exogeneous increase in supply. The latter exercise was motivated by the possibility of a substantial long run source of supply of cobalt from seabed mining.

In this context, we study the world cobalt market by discussing the following topics:

In Chapter I, the general nature of the cobalt market is discussed. The production sources, consumption by region and end uses, and past prices of cobalt have been analysed.

In Chapter II, first the theoretical model has been developed. This is followed by a discussion of estimation techniques. The chosen technique is then used to estimate demand equations for United States by end use categories.

Chapter III analyses the producer price behaviour. Two hypotheses frequently advanced are stated and empirically tested.

Chapter IV presents the estimated demand equations for some major industrialised countries and a demand equation for the noncommunist world as a whole.

In Chapter V two one period simulation experiments are performed. They are, the effect of a marginal cost pricing policy by producers and second, the effect on price of an exogeneous increase in supply (possibly arising from seabed mining).

Chapter VI summarises the important conclusions, and the study's contribution to existing literature.

1.1 Production

Cobalt belongs to the family of non ferrous alloys. It is a hard, brittle metal with an atomic number 27. It closely resembles iron and nickel in appearance. It has a melting point of 1495°C and a boiling point of 2870°C .⁽¹⁾ Cobalt occurs in the minerals cobaltite, smaltite and erythrite and is usually recovered as a byproduct of lead, iron, copper, nickel and silver ores.⁽²⁾ The concentration of cobalt in these ores is relatively small. For example, the ores that were mined in 1978 contained only 0.1 to 0.5 percent cobalt. Copper and nickel ores have relatively higher concentration of cobalt as compared to iron, zinc, lead, silver and uranium ores. Cobalt has been produced as the principal metal in only two places, the Bou-Azzer district in Morocco and the Blackbird district of Lemhi County in Idaho, United States. The latter mine was closed down in 1959 but plans were made to reopen it in 1979.

Cobalt's special properties make it particularly useful in metallic applications, for production of magnetic alloys, superalloys and hard alloys resistant to abrasion, corrosion and high temperatures. Cobalt is also used as an alloying material in tool and die steels. The non metallic compounds account for about 25 percent of total cobalt consumption in salt form. The salts are used as dryers in paints, as decolorizers for glass, and in the production of permanent blue colours in porcelain and enamel.

(1) Metal Statistics (1977)

(2) Metal Statistics (1979)

A variety of methods are used to extract cobalt from the ore. In the largest deposits of Zaire open pit mining is generally employed. ⁽¹⁾ The cobalt ore is usually concentrated prior to processing.

Between World War I and 1924 Canada was the only large producer of cobalt in the world accounting for 75 % of total production. Between 1924 and 1947 Deloro refinery in Canada, Zaire and Morocco together accounted for about 76 % of total production. After World War II, noncommunist world production was concentrated in four countries: Zaire, Zambia, Morocco and Canada. The major producers in these countries were Gécamines in Zaire, Rhokana in Zambia, Bou-Azzer in Morocco, International Nickel Company and Falconbridge in Canada.

In 1978, in terms of world mine output, Zaire topped the list of producers with a mine output 41 % of the total. New Caledonia (Oceania) was second with 13 %, Australia third with 11 %, Zambia fourth with 6 % and Canada fifth with 3 %. Mined output of cobalt by major producer countries in 1978 is displayed in table 1.1.

(1) For instance, see Burrows (1971, p. 18).

Table 1.1 World Cobalt Mine Production, 1978
(Thousand Pounds)

Region	Production in 1978
North America:	
Canada	2,000
Cuba	<u>3,600</u>
Total	5,600
Europe:	
Finland	3,000
U. S. S. R.	<u>4,400</u>
Total	7,400
Africa:	
Botswana	400
Morocco	4,000
Zaire	29,000
Zambia	<u>4,000</u>
Total	37,000
Oceania:	
Australia	7,600
New Caledonia	9,200
Philippines	<u>2,400</u>
Total	19,200
World Total:	<u>70,000</u>

Source: Scott (1979)

It can be seen from table 1.1 that cobalt mine production is largest in Zaire, followed by New Caledonia and then Australia.

Estimated current world production of refined metal is shown in table 1.2.

Table 1.2 World refined Metal Production (Thousand pounds)

Countries	Years	
	1977	1978 ^P
Canada	1,012	1,000
Finland	2,172	2,000
France	1,880	2,400
Fed. Rep. of Germany	1,770	800
Japan	2,410	4,100
Norway	1,554	1,500
U. S. S. R ^e	4,200	4,000
United Kingdom	1,780	1,200
United States	508	650
Zaire	22,520	29,000
Zambia	<u>3,754</u>	<u>4,000</u>
Total:	<u>42,560</u>	<u>50,700</u>

^e Estimated; ^P Preliminary

Source: Scott (1979)

Zaire leads again, accounting for more than half of total world refined metal production. It is followed by Japan, Zambia and U. S. S. R. The production structure of the major producer Zaire and some other noncommunist producers is discussed in the next section.

Zaire

In Zaire cobalt is produced mainly as a byproduct of copper. Copper accounts for about 80 % of Zaire's value of mineral production and cobalt for about 10 %. Between 1973 and 1978, copper production in Zaire remained relatively constant, while cobalt production declined. However, with the new surge in cobalt prices production of cobalt is expected to pick up. Government-owned company Gécamines mines most of the cobalt, and SOZACOM, another official agency markets most of it. Three major bottlenecks faced by these companies in recent years have been, insurgent attacks in the mining region of Shaba Province, transportation and finance.

Zambia

Cobalt is also a byproduct of Zambia's copper industry. There are two major state-owned mining companies in Zambia: Nchanga Consolidated Copper Mines Ltd. (NCCM) and Roan Consolidated Mines Ltd. (RCM). ⁽¹⁾ Since 1969, the Zambian government has been nationalizing its metals and mining industry. ⁽²⁾ However, nationalization has not affected the output of cobalt adversely. As with Zaire, lack of adequate transportation has proved to be a major problem.

(1) See Scott (1979, p. 3).

(2) See Charles River Associates Report (1976, p. 6).

Morocco

Deposits containing cobalt in percentages as high as 1.2 % are found in Bou-Azzar and El Graara areas. Cobalt accounts for more than 75 % of the value of Bou-Azzar's ore production. Société Minière de Bou-Azzar et du Graara is the sole producer of cobalt in Morocco. Most of the cobalt produced is exported to France.

Canada

The three major producers in Canada are International Nickel Company, Falconbridge and Sheritt-Gordon. They all produce cobalt as a byproduct of nickel production. Cobalt traditionally was not mined in very significant quantities by any of these firms so the development of any new deposit was not likely to be affected very much by price. However, with rising cobalt prices deliveries of cobalt by INCO and Falconbridge have gone up. Deliveries by INCO were up 134 % in 1976 from those of 1975 and Falconbridge deliveries were up 52 % in the same year. ⁽¹⁾ The bulk of the cobalt reserves are held by International Nickel Company.

Australia

In Australia cobalt is mined principally as a byproduct of nickel from Greenvale nickel laterite deposits. The deposits are mined by Freeport Queensland Nickel incorporated and Metals Exploration Queensland, Pty. in Greenvale. Repairs and re-design of ore-processing units at the Greenvale nickel-cobalt metallurgical plant in Queensland resulted in increased efficiency and production close to capacity.

(1) Minerals Yearbook (1976)

1.2 Other Potential Sources

In addition to land based mining there are four additional potential sources of supply. In the short run, these are secondary recovery of cobalt from scrap and sales from United States Strategic Stockpiles. In the medium run, expansion of capacity of existing mines could increase cobalt production. Finally, in the long run, new land based and sea-bed mines could be established.

Data on secondary sources of supply of cobalt is very meagre and unreliable. Whatever data does exist is only for the United States. Table 1.3 reports the figures for recovery of cobalt from scrap.

Table 1.3 US Secondary Supply (Thousand pounds)

Year	Secondary Supply
1969	328
1970	69
1971	125
1972	197
1973	264
1974	270
1975	342
1976	329
1977 ^P	507
1978 ^e	1,036

P Preliminary; e Estimated
Source: Scott (1979)

The data presented above suffers from many defects, the most serious being that it has been collected by questioning consumers alone about their purchases of secondary cobalt. No questionnaires have been sent to scrap processors. Information available indicates that there are three sources from which most of the cobalt is recovered. These are waste materials discarded in manufacturing superalloys, high-temperature alloy components of jet engines that are replaced from time to time and spent petroleum catalysts used in desulfurization of crude oil. ⁽¹⁾ It has been estimated that secondary or scrap sources account for only about 3 % of total annual cobalt consumption in the United States. ⁽²⁾ Thus, it would seem that secondary recovery would not be a significant source of additional supply in the future. It is worth noting, however, that during 1979 about 900 metric tons of cobalt was recycled from scrap, which represents nearly 10 % of U. S. consumption. This high rate maybe due to the very high levels which cobalt prices touched in this year.

Information on stocks is available only for the United States. Consumer stocks, as of December 31 , 1976 were estimated at 3,180 thousand pounds, and industry stocks at 1,751 thousand pounds of contained cobalt. These commercial stockpiles represent a mere fraction of the GSA stockpile. The total inventory of cobalt in the stockpile as of December 31st, 1976, excluding materials sold but not delivered, was 40,950.635 thousand pounds. Deliveries from the stockpile totaled about 6,698 thousand pounds. ⁽³⁾ Sales from the GSA stockpile have been occurring on an average rate of half of U. S. consumption. They could represent a fairly significant source of supply of cobalt for the next few years.

(1) Scott (1979)

(2) Mineral Commodity Summaries (1979)

(3) Minerals Yearbook (1976)

In the intermediate run, additional equipment could be installed in mines in which cobalt can be obtained as a byproduct. The time required to install new equipment usually ranges from one to four years. Capital costs in this option are quite high especially when the ores identified have cobalt in very small concentrations. The operating cost per unit of cobalt must be weighed against the expectations of profits which in turn are largely a function of the price of cobalt. It appears that cobalt price increases that began in 1975 and accelerated in 1978 have brought these available supply sources into production. ⁽¹⁾ There exists the possibility of extracting cobalt as a byproduct of nickel since several nickel mines are scheduled to come into operation in the near future. However, it is doubtful that such additions would constitute a significant source of supply.

Traditionally, in the long run the decision to start new land based mines depended to a large extent on the prices of copper, nickel and other major metals since cobalt was mined as their byproduct. However, recently the continuing trend of rising cobalt prices has given cobalt the status of a genuine co-product. If producers expect this trend to be maintained then opening up of future mines would depend as much on the value of production accounted for by cobalt as that of any other metal. For example there are definite plans to start production of cobalt in the West Panther Creek area of Idaho State. Vorondo Mines of Canada also plan to reopen an old cobalt mine and produce 4.4 million pounds of cobalt a year by 1984.

Table 1.4 below gives the identified world resources of cobalt.

(1) Mining Annual Review (1979, p. 80)

Table 1.4 Identified World Cobalt Resources, 1978
(million pounds)

	Estimated reserve base	Other identified resources	Total identified resources
North America:			
United States	0	1,700	1,700
Canada	66	480	550
Cuba	240	2,100	2,300
Total	300	4,300	4,600
Europe:			
Finland	40	10	50
U. S. S. R.	460	40	500
Total	500	50	550
Africa:			
Botswana	58	12	70
Morocco	28	2	30
Zaire	1,000	500	1,500
Zambia	250	520	770
Total	1,300	1,000	2,400
Oceania:			
Australia	110	540	650
New Caledonia	600	250	850
Philippines	420	30	450
Total	1,100	820	2,000
World total, land based	3,200	6,200	9,600
World total, seabed nodules	0	500,000	500,000

Source: Scott (1979)

Short of any major cobalt operations such as those in Idaho State and supply additions from new land-based mining, the possibility of seabed mining of manganese nodules in the Pacific may prove to be the most substantial long run source of supply. It is believed that there are about 76 billion tons of nodules in the Pacific with about 2.4 % recoverable cobalt content which means a potential supply of cobalt of about 1.8 billion tons. This estimate exceeds many thousand times the current world production. Hence, the projected additions are substantial.

The manganese nodules are composed of manganese, cobalt, copper and nickel with manganese content being the highest, approximately 24 %. There are major barriers to mining these reserves. The main obstacle is the negotiations in the United Nations concerning the Law of the Sea. The negotiations revolve around the extraction and processing of the nodules. There is also disagreement concerning the nature of restrictions to be placed on seabed mining. In an attempt to provide a more stable environment, the U. S. Congress has passed legislation that would allow seabed mining to begin by 1988 if the Law of the Sea negotiations are not completed. Some factors that could hasten the extraction of minerals from manganese nodules are, an increase in land based mining costs, producer nations using their source of supply as a weapon to gain concessions from consumer nations, and price increases which are not due to rising costs alone. Considerable research is also in progress to develop economically efficient techniques for mining and processing cobalt-bearing nodules from the ocean floor. Many patents have been issued to encourage further research. However, it is doubtful that seabed mining would become an important source of mineral supply for at least another decade.

1.3 Consumption

The state of the statistics for consumption of cobalt is very unsatisfactory. No statistics for the level and trend of cobalt consumption are published for the world as a whole because the Eastern bloc countries estimates are merely guesses. Even in the Western world because production and foreign trade of cobalt and its compounds are to a large extent kept secret, the estimates of consumption arrived at are again only rough estimates. These estimates too have been published for cobalt consumption only in the markets supplied by Western producers. According to this, consumption in the Western world, including deliveries to the Eastern bloc, rose from 21,500 tons in 1966 to 27,000 tons in 1969 and 1973. The peak was reached in 1974 with cobalt consumption of 27,500 tons. In 1976 the consumption was only 23,000 tons. ⁽¹⁾ The figures for the consumption of cobalt throughout the world for years 1966 - 1976 are presented in the appendix.

Looking at shares, the Western world's share of world cobalt consumption between 1966 and 1974 remained constant at around 80 %. But with the recession of 1974 - 1975 the consumption shares of Western Europe fell to 26 %, and of USA to 34 % in 1976. On the other hand, there was an increase in the Asian share in world consumption from 11 % to 14 %.

In table 1.5 the share of the continents and of selected countries in cobalt consumption is shown for the years 1966 and 1976.

(1) Cobalt, a report published in 1978 by the Federal Institute for Earth Sciences and Raw Materials and the German Institute for Economic Research.

Table 1.5 Shares of the continents and of selected countries in cobalt consumption in 1966 and 1976 (%)

Region	<u>1966</u>	<u>1976</u>
Federal Republic of Germany	7.6	8.0
France	4.0	4.1
Great Britain	11.2	5.3
Italy	2.5	1.3
Netherlands	1.3	1.5
EEC countries	27.3	21.1
Sweden	1.4	2.1
Europe excluding Eastern bloc	31.2	26.4
Japan	9.8	12.5
Asia excluding Eastern bloc	10.8	14.0
Africa	0.2	0.4
USA	36.6	31.8
America	38.5	34.4
Australia	0.3	0.3
Western world	81.0	75.5
Poland	1.1	1.7
USSR	13.5	15.9
People's Republic of China	2.3	3.5
Eastern bloc	19.0	24.5
World total	100.0	100.0

Source: "Cobalt", Vol.XI, "Investigations into Supply and Demand of Mineral Raw Materials", 1978, Federal Institute for Earth Sciences and Raw Materials and German Institute for Economic Research

The USA in 1976 was the largest cobalt consumer with a share of about 32 %. The USSR was second with 16 % and Japan third with 13 %. It is evident from table 1.5 that consumption (unlike production) is not concentrated. This could be because consumption is generally at the firm level and there are a large number of firms which consume cobalt.

Data on consumption of cobalt by end use exist only for the United States. These figures are reported below in table 1.6.

Table 1.6 Consumption of Cobalt in United States by End Use, 1978^P

Use	Cobalt consumption (thousand pounds)
Superalloys	4,251
Magnetic Alloys	3,752
Cutting and wear resistant materials	1,654
Welding and hardfacing rods and materials	668
Catalyst	405
Salts and driers	4,073
p = preliminary	

Source: Metal Statistics (1979)

In terms of broad categories major uses in 1978 were transportation (aircraft) 23 %, electrical (magnets) 22 %, machinery (principally cutting tools) 16 %, paints (mainly driers) 16 %, ceramics 13 %, and chemicals 8 %.

Superalloys

High temperature alloys (superalloys since 1968) have been the most important end use of cobalt in the postwar period. There are four types of superalloys currently in use, the most popular being nickel-base and cobalt-base alloys. These have the properties of high strength at temperatures above 1200⁰ F, resistance to corrosion by oxidation, resistance to contamination by alkali, acid and high thermal conductivity. Cobalt and nickel are complements for the most part in both the alloys, but there is a finite range in which one metal may be substituted for the other in many applications. The dominant uses of superalloys have been in the manufacture of gas turbines, primarily for jet engines. The quantity of cobalt contained in a medium-large engine is reported to be about 100 pounds, with about twice that much needed initially and subsequently machined away. (1)

In recent years usage has extended to turbines for generating electricity, pumping natural gas and propelling marine aircraft. It is estimated that as much as 30 % of the cobalt used in superalloys is now utilized in turbines for power generation since the technology was first introduced in 1965. These turbine-powered generators primarily supplement larger base load installations during periods of peak load.

(1) Charles River Associates (1976, p. 23); Burrows (1971, p. 60)

Magnetic Alloys

Cobalt has wide applications in magnetic alloys since cobalt additions raise the saturation magnetization of iron. The magnetic alloys are in the form of magnetic steel and Alnico (aluminium-nickel-cobalt) alloys. Cobalt containing Alnico magnets are used in telecommunications, meters, loudspeakers, separator magnets, motors and generators. ⁽¹⁾ Cobalt magnetic steel is generally used where a high coercive force is not needed and where considerations of weight are not important, such as in industrial motors, relays, magnetos and meters. ⁽²⁾

The approximate breakdown of the use of cobalt magnets is given in table 1.7.

Table 1.7 Use of Cobalt Magnets (in percent)

Category	Percentage
Loudspeakers	25
Rotating electric machines	25
Indicating devices	25
Telecommunications	20

Source: Scott (1979)

With the introduction of ceramic magnets in 1957 Alnico magnets have lost a considerable share of the market for loudspeakers. Ceramic magnets made from barium or strontium ferrite are cheaper and have better magnetic properties but on the other hand they also have greater "magnetic leakage" than Alnicos. Hence, while these less expensive ceramic magnets

(1) Burrows (1971, p. 67)

(2) *ibid*, p. 71

have captured most of the market in loudspeaker applications, cobalt magnets have retained their majority in television and radio applications where magnetic leakage can seriously interfere with the reception of sets.

Tool cutting Steels and Wear Resistant Materials

Tool steels and cemented carbides are the major components of this end use. Cold work and hot work tool steels have high resistance to wear and abrasion. Both kinds of tool steels are primarily used for dies and punches. Tool steel of H 19 variety containing cobalt competes with another variety, H 14, which contains more tungsten and molybdenum. High speed steels are primarily used as a cutting tool material in high speed machining. There are two main types of high speed steels, tungsten steel and molybdenum steel. To both kinds of steel 5 to 12 % of cobalt is added to improve their hot hardness. (1) Molybdenum steel has a generally higher cobalt content. Principal application for high speed steels is in machining iron, steel and nonferrous metals. When price of cobalt rises high speed steel maybe substituted for tungsten steel so tungsten could be an indirect substitute for cobalt. However, high speed steels also compete with stellites which contain a high percentage of cobalt but a low percentage of cemented tungsten carbide which in turn contains only small amounts of cobalt.

Cemented carbides are used in mining and drilling operations for blanking, forming, wire drawing, heating dies, shafts, valves and drill bits. Cobalt content of cemented carbides varies from 3 to 25 %. Here, cobalt has no substitute as a binder and cobalt represents only a minor percentage of the value of cemented carbides.

(1) Burrows (1971, p. 80)

Welding and Hardfacing Rods and Materials

Cobalt base alloys effectively hardface materials at temperatures above 1200° F. These alloys are used to hardface valves, bearings and bushings. They also find applications in welding, especially of jet engine components. It is reported that there has been substitution away from cobalt in this end use since 1968. (1) Cobalt has been found to be a very good substitute for nickel for electroplating, where a half-nickel half-cobalt plating is superior to the all-nickel plating except for corrosion resistance.

The principal competing group of alloys for the cobalt base alloys is the tungsten carbide compounds. However, these compounds exhibit lower toughness, impact resistance and oxidation resistance. Within the group of cobalt-base alloys there have been some attempts at substitution of nickel, iron and molybdenum for cobalt but they always result in lowering hot hardness. Hence in this end use there is no important substitute for cobalt.

Other Metallic Uses

Cobalt metal has uses other than those listed above. Cobalt-containing alloys are used in metal-to-ceramic seals, metal-to-glass seals, springs, diaphragms, pivots. (2) The non-metallic uses are split between chemical and ceramic uses, and salts and driers. Since 1968 the use of cobalt as a catalyst has become very important.

(1) Charles River Associates (1976, p. 14)

(2) Burrows (1971, p. 91)

Salts and Driers

Cobalt oxides are used in paints, ceramics and varnishes as decolorizers, dryers and oxidizers. The rubber industry employs organic cobalt compounds to increase the adherence of steel to rubber in steel belted radial tyres. It is reported that the introduction of synthetic latex paints may have had a negative effect upon the use of salts and driers in paints. (1) But the development in 1960 of a new manganese lead drier may have offset this effect. In 1971 a federal regulation was passed to reduce the useage of lead in interior paints and the paint industry began doing so in 1969 in anticipation of the regulation; the effect was to increase the use of cobalt as a drier in place of lead. (2) In drier applications, manganese and lead each can act either as a substitute or as a complement.

Catalyst

The principal use of cobalt in chemical industry is as a catalyst. A cobalt-molybdenum-alumina compound is a common petroleum desulfurization catalyst. Molybdenum is a complement and nickel and tungsten together are substitutes for cobalt. It has, however, been found that the use of nickel reduces octane and requires higher pressures to be effective. (3)

Other nonmetallic uses

These include use of cobalt in pharmacology, ceramics, as a dietary supplement for animals, as a radio isotope to substitute for radium in therapeutic purposes and the use of radio cobalt to detect cracks in metal.

(1) Charles River Associates (1976, p. 14)

(2) *ibid*, p. 28

(3) Scott (1979, p. 14)

1.4 Future Trends in Demand (1)

The outlook for future applications for cobalt appears to be uncertain.

In the field of transportation, automobile makers are considering replacing ferrite magnets with cobalt rare-earth magnets. In comparison with Alnico magnets, a net cobalt saving of 30 % would be achieved. An international workshop was held at the University of Dayton to review the potential of rare earth magnets. (2) A relatively new manganese-aluminium-carbon alloy developed by a Japanese company will also be used as a substitute for Alnico applications. Hence, the trend away from Alnico application is expected to continue in the future.

In the area of wear-resistant and hard facing applications, two principal alloy manufacturers in 1978 announced the development of effective substitutes for high cobalt alloys.

On the positive side, commercial aircraft manufacturing is expected to increase substantially, increasing the demand for superalloys in the production of jet engines. Other developments in transportation which could significantly increase demand include the possible use of cobalt in nickel-zinc batteries in electric vehicles and the use of cobalt catalyst in the production of synthetic fuel. In the field of magnets possible new uses in 1980s include fan and alternator motors, tire pressure gauges and seat actuators.

(1) This section relies heavily on Scott (1979)

(2) Metal Statistics (1977)

Scott (1979) forecasts that the primary demand for cobalt in the United States and the rest of the world would grow at a rate of 3.3 % and 3.4 % respectively. Supply and demand it is expected would balance in the long term. However, in the short and medium run, pending commercial exploitation of cobalt-bearing manganese nodules demand could exceed supply. Supply is likely to be small on account of weak nickel and copper markets which will result in the curtailment of some cobalt projects.

1.5 Prices

Quoted cobalt prices are given in table 1.8.

Table 1.8 Time-Price Relationship for Cobalt*

Year	Average annual price, Dollars per pound	
	Actual prices	Based on constant 1978 Dollars
1957	2.03	4.75
1958	2.00	4.60
1959	1.77	3.99
1960	1.54	3.41
1961	1.50	3.29
1962	1.50	3.23
1963	1.50	3.19
1964	1.50	3.14
1965	1.62	3.32
1966	1.65	3.27
1967	1.85	3.56
1968	1.85	3.41
1969	1.89	3.31
1970	2.20	3.66
1971	2.20	3.48
1972	2.45	3.73
1973	3.00	4.31
1974	3.46	4.54
1975	3.98	4.76
1976	4.44	5.05
1977	5.58	5.99
1978	11.53	11.53
1979 (September)	25.00	

* Prices are weighted averages for each year.

Source: Scott (1979)

It can be seen from the table that the price of cobalt has risen from \$ 1.50 per pound in 1964 to \$ 25.00 per pound in September 1979. In the period 1973 - 1978, the actual price of cobalt rose by 30 % per year and by 22 % per year in constant 1978 Dollars. The total increase for actual price and price based in constant dollars is estimated to be 733 % and 480 % respectively.

On the supply side cobalt market is dominated by relatively few producers and marketing agents. On the demand side, there are a large number of buyers, mostly at the firm level. In this environment, the price of cobalt is generally set by SOZACOM, the marketing agency of Gécamines in Zaire. This price is then followed by all the cobalt producers. It is not clear whether the major producers in the cobalt industry cooperate to maximize profits or whether SOZACOM sets the price of cobalt to maximize its own profits. Given the concentrated nature of ore production and dominance by Zaire it has been argued by Burrows that Zaire sets the world price in order to maximize its own profits. ⁽¹⁾ This proposition he then supports by econometric analysis. It is argued in another study that supply of cobalt from other sources is inelastic since non-Zaire cobalt is a minor byproduct of other mining output. Given these conditions, Zaire determines the price taking into account current demand conditions, the amount of cobalt mined outside Zaire and USA releases from stockpiles to maximize its own profits. ⁽²⁾

Burrows indicates that in the period 1946 - 1968 government purchases have been most important in explaining movements in cobalt prices. ⁽³⁾ Since 1964, aside from increased costs of

(1) Burrows (1971, p. 24 - 25)

(2) Charles River Associates (1976, p. 4)

(3) Burrows (1971, p. 7)

mining, refining and general inflation other factors have been, the removal of cobalt from the list of commodities prohibited from being shipped to Sino-Soviet nations, increase in U. S. consumption in the period of escalation of Vietnam war, nationalization of mines in Zaire, Canadian nickel strike, stoppage of USA stockpile sales in 1976 and reduced copper and nickel production. (1)

It appears therefore that the price of cobalt responds to exogenous events and major shifts in aggregate demand but is stable in the face of small fluctuations in demand for cobalt.

(1) In March 1981 Zaire announced a 20 % reduction in cobalt prices. SOCACOM, the marketing agency of Zaire, reduced prices from \$ 25 per pound to \$ 20 per pound. Prices were reduced to lower the stockpiles totalling 5000 tonnes. Financial Times, March 3, 1981

II EMPIRICAL ANALYSIS OF COBALT CONSUMPTION

Consistent time-series data on end-use categories is available only for the United States. The word "end-use" is really a misnomer because end-use data reflect consumption of cobalt in various intermediate products like superalloys, magnetic alloys and salt and driers. What is actually needed is data on the use of cobalt in final products such as jet engines, electrical equipment, welding electrodes etc. Unfortunately this information is not available. Hence demand functions are estimated for intermediate products.

In this chapter first the estimation and specification of demand functions in general is discussed - and then the empirical results for each demand function are presented. The results are analysed and the elasticities computed.

2.1 Specification and Estimation of Demand Functions

The purpose of demand analysis is to obtain short run and long run elasticities with respect to the price of cobalt, its substitute (where it exists) in different end uses and activity variables of cobalt consumption. There are basically two ways of estimating the required elasticities. These are first, by running an aggregate demand function and second, by running separate demand functions for each of the end uses and then using some weighting procedure to get aggregated estimates of the relevant elasticities. Econometrically, however, it is expected that the two estimates obtained would not be identical. In the next section we use both approaches, though it should be noted that the second approach is likely to be more appropriate for the following reasons.

First, problem arises from the specification of the aggregated demand function. If we specify a linear functional form then implicitly we are assuming that the demand function for each of the end use categories is linear. It is of course not only possible but highly likely that some of the end use categories could perhaps be characterized better by a non-linear relationship. Arbitrary aggregation would lead to the inevitable aggregation bias in a regression relationship ⁽¹⁾.

Second, the aggregated demand function consists of a large number of diverse end uses and each end use has a usually different activity variable and sometimes a different substitute variable for cobalt. In running the aggregated demand function it is impossible to include all possible activities and substitute variables because the data set consists of no more than 30 observations and to obtain efficient estimates it is necessary to conserve as many degrees of freedom as possible.

Third, inclusion of too many price and income variables will lead to the problem of multicollinearity and inefficiency of the estimates. Despite the three problems noted above, the estimation of an aggregate demand function in its simplest form was carried out to a) serve as a norm of comparison for the weighted estimate and b) to convey a general picture of the cobalt market.

(1) For a discussion of aggregation bias see Maddala (1971, Ch. 10)

2.2 SPECIFICATION

2.2.1 Specification of Functional Form

The first problem here is one of deciding whether to use a linear or a log-linear functional form. The linear functional form of the type

$$Q^C = a_1 + b_1P + c_1Y + u_1$$

where

Q^C is the consumption of cobalt,

P is the price variable,

Y is the income variable,

u is the disturbance term

assumes that

$$\partial Q^C / \partial P = b_1 \text{ and } \partial Q^C / \partial Y = c_1.$$

That is, a given absolute change in P or Y has the same absolute effect on consumption for all value of P and Y . The log-linear form assumes a relationship of the kind

$$Q^C = a_2 P^{b_2} Y^{c_2} U_2.$$

That is, the effect of P and Y on Q^C is multiplicative. This when transformed into log becomes

$$\ln Q^C = a_2 + b_2 \ln P + c_2 \ln Y + \ln U_2.$$

Note that here η_p , elasticity of demand is defined as b_2 , the coefficient of $\log P$ and η_Y , the income elasticity of demand is defined as c_2 , the coefficient of $\log Y$. These elasticities are assumed to be constant. Therefore, a percentage change in P or Y results in a constant percentage effect on consumption for all values of P and Y .

A priori it is difficult to judge whether the demand function should be in linear or non linear form. One possibility could be to use Box-Cox transformation to search for the appropriate functional form ⁽¹⁾. However, the approach was not available in the computer package at the time of this study. It was therefore decided to run both linear and loglinear forms and to choose between the two on the basis of criteria such as values, and the Durbin-Watson statistic. One must note here that the criteria cannot be a comparison of R^2 or R^2 adjusted for degrees of freedom calculated from the residual sum of squares because of the differences in the functional forms. The Durbin-Watson statistic was chosen as one of the criteria because it has been noted recently in many papers that a priori, the correct specification would give a better value of the Durbin-Watson statistic in the sense of it being closer to 2 ⁽²⁾.

2.2.2 Specification of Lag Structure

The choice of the functional form is only one problem encountered in econometric estimation. The other question that needs to be tackled is the appropriate lag structure to be used. One cannot expect consumption to adjust fully to a change in price

(1) For instance, see Boyland et al (1980) for an application of this procedure to the estimation of import demand functions.

(2) For the case of negative autocorrelation the closeness of the Durbin-Watson statistic to 2 is determined by first subtracting the printed value from 4.

during the first time period. It is reasonable to assume that adjustment would occur over a period of time. ⁽¹⁾

First, prices of cobalt-containing materials would react only after a lag to changes in cobalt prices. For example, prices of superalloys would be affected after a lag and then there would be another lag before the prices of jet engines or turbines change. Second, much depends on the consumer expectations. If they expect the price changes to persist then consumption behaviour would be altered. Since substitution of other metals is both costly and time consuming, producers of jet engines, for example, would change over to alloys with less cobalt only if higher prices are expected to persist. Third, actual substitution itself takes time.

To take lags into account, the simple linear demand function would have to be respecified as follows:

$$Q^C = a_1 + \sum_{i=0}^n b_{1i} P_{-i} + c_1 Y + U_1$$

The log-linear demand function would now take the form

$$\ln Q^C = a_2 + \sum_{i=0}^n b_{2i} \ln P_{-i} + c_2 \ln Y + \ln U_2$$

The next step would be the specification of the lag structure. Two types of lag structures have been widely used in the existing literature. These are, the geometric lags and the "inverted-V" lags. A number of econometric studies on metals seem to favour the use of geometric lags. ⁽²⁾ A geometric lag structure assumes that the effects of changes in price on consumption should be greater the closer they are in time to the consumption decision.

(1) Burrows (1971)

(2) See Fisher, Cootner and Bailey (1971) and Burrows (1971)

The Koyck or geometric lag ⁽¹⁾ can be formulated as a stock adjustment model along the following lines. Denote the amount of consumption of cobalt in year t by Q_t^C and the price paid by consumers by P_t . Given the price, consumers would like to consume an amount Q_t^{C*} which depends on P_t according to the long run demand equation, for example

$$Q_t^{C*} = a_1 + b_1 P_t \quad (1)$$

However, since it takes times to adjust consumption, the consumers do not immediately move to the new value Q_t^{C*} in response to a new value for price, but only begin to move in that direction. If it is assumed that it is only possible to move some fixed fraction, μ , of the desired distance in any year, then

$$Q_t^C - Q_{t-1}^C = \mu(Q_t^{C*} - Q_{t-1}^C) \quad 0 < \mu < 1 \quad (2)$$

Substituting (1) into (2) and rearranging terms:

$$Q_t^C = \mu a_1 + \mu b_1 P_t + (1 - \mu) Q_{t-1}^C \quad (3)$$

Lag equation (3) and obtain an expression for Q_{t-1}^C , then lag it again and obtain one for Q_{t-2}^C , and so forth. Repeated substitution of the lagged versions into (3) yields

$$Q_t^C = a_1 + \mu b_1 \sum_{\theta=0}^{\infty} \lambda^{\theta} P_{t-\theta}, \quad \lambda = 1 - \mu, \quad (4)$$

so that consumption in year t depends on present and past prices with the weights given to lagged prices, declining geometrically with the length of the lag. In this model, the short-run effect of price on supply is given by μb_1 , but the long-run

(1) See Koyck (1954) and Nerlove (1958)

effect is b_1 itself. If μ is small, so that adjustments take place slowly, then the long-run effect can be larger than the short-run effect.

It is sometimes argued that an adaptive expectations model would be more realistic as compared to the stock adjustment model. However, it can be shown that this kind of expectation formation also leads to the formulation (4) above. Suppose the demand function is given by

$$Q_t^c = a_1 + b_1 P_t^*, \quad (5)$$

where P_t^* denotes expected long-run price. Suppose further that price expectations are formed by revising earlier expectations in the direction of actual prices, according to the relation

$$P_t^* - P_{t-1}^* = \mu (P_t - P_{t-1}^*), \quad 0 < \mu < 1 \quad (6)$$

Here μ is no longer the speed of adjustment of supply, but rather the speed of adjustment of price expectations. Equation (6) is equivalent to

$$P_t^* = \mu P_t + (1 - \mu) P_{t-1}^* \quad (7)$$

so that expected price this year is a weighted average of expected price last year and actual price. Repeated lagging of (7) and substitution for lagged values of P_t^* yields

$$P_t^* = \mu \sum_{\theta=0}^{\infty} \lambda^{\theta} P_{t-\theta}, \quad \lambda = 1 - \mu, \quad (8)$$

so that expected price is also a weighted sum of present and lagged prices, with the weights declining geometrically with the length of the lag. Substitution of (8) into (5) now yields (4).

Despite the fact that two models have been shown to be equivalent as regards to the formulation of the final consumption equation, econometrically, however, there is a difference in the structure of the disturbance terms. The stock adjustment model has a spherical disturbance term but the adaptive expectations model has a disturbance term which is of the moving average type, i. e. the adjacent errors are correlated but errors two or more periods distant are uncorrelated.

An alternative to the geometrically declining lag distribution is the "inverted V" distribution. Here the shape of the lagged distribution as well as the weights can be specified in advance. The independent price variables, price of cobalt and/or its substitute can then enter a regression equation as a weighted average of present and past prices constructed with the pre-specified weights. An "inverted V" lag distribution seems realistic for price of cobalt because one would expect there to be a very small effect on consumption in the first year, then the effect to increase in the subsequent years to reach a maximum, and then to taper off. In general, a lag distribution on price can be expressed as:

$$Q_t^C = a + \sum_{i=1}^j b_i P_{t-i} + u_t$$

In terms of weights w_i this relationship is

$$Q_t^C = a + b (w_1 P_{t-1} + w_2 P_{t-2} + \dots w_j P_{t-j}) + u_t$$

Hence

$$b_1 = bw_1.$$

If the number of lags, j , is even, then the "inverted V" distribution for P_t with j lags

$$(P_t, j) = \frac{(1 + \frac{j}{2}) P_{t-\frac{j}{2}} + \sum_{i=0}^{\frac{j}{2}-1} (i+1) (P_{t-i} + P_{t-j+i})}{(1 + \frac{j}{2}) + 2 \sum_{i=0}^{\frac{j}{2}-1} (i+1)}$$

If the number of lags, j , is odd, then

$$(P_t, j) = \frac{\sum_{i=0}^{\frac{j-1}{2}} (i+1) (P_{t-i} + P_{t-j+i})}{\frac{j-1}{2} + 2 \sum_{i=0}^{\frac{j-1}{2}} (i+1)}$$

For the case of $j = 3$, the lag distribution is

$$\begin{aligned} (P_t, 3) &= \frac{\sum_{i=0}^1 (i+1) (P_{t-i} + P_{t-3+i})}{\frac{1}{2 \sum_{i=0}^1 (i+1)}} \\ &= \frac{P_t + P_{t-3} + 2(P_{t-1} + P_{t-2})}{2 [1 + 2]} \\ &= \frac{P_t + 2P_{t-1} + 2P_{t-2} + P_{t-3}}{6} \\ &= \frac{1}{6} P_t + \frac{1}{3} P_{t-1} + \frac{1}{3} P_{t-2} + \frac{1}{6} P_{t-3} \end{aligned}$$

The demand function to be estimated for $j = 3$ will then be

$$Q_t^C = a + b (0.17 P_t + 0.33 P_{t-1} + 0.33 P_{t-2} + 0.17 P_{t-3}).$$

The interpretation of this lag structure is that, if the price of cobalt increases by one dollar and say, X is the cobalt consumption, then consumption would reduce by $0.17 bX$ pounds in the first year, by $0.33 bX$ pounds more during the second year and by $0.33 bX$ pounds more in the third year. But in the fourth year consumption would fall by $0.17 bX$. The long-run reduction in the annual consumption rate would be bX pounds of cobalt.

2.3 Estimation Techniques

The estimation technique depends on the nature of the lag distribution postulated. Estimation of equations with an "inverted V" distribution or with only current price of cobalt as an explanatory variable was carried out using the simple instrumental variable technique. The rationale for using this technique is that the demand functions are a part of the simultaneous model of the cobalt market with price of cobalt being determined endogeneously in the system of equations. If equations (such as those with "inverted V" lags) in which the current price of cobalt also appears as an independent variable are estimated using ordinary least squares then the estimates obtained would be biased.

The choice of appropriate instruments is crucial. Any exogenous instruments chosen would give unbiased estimates of the coefficient of price of cobalt as long as they are not correlated with the error term, but only good instruments would give efficient estimates in the sense of their having smaller variances. Therefore, first, the instruments chosen

must be truly exogeneous in the sense that the covariance between the error term and the instrumental variable must be zero. Second, the instruments should also vary substantially enough to have their impact on both the regressor and the regressand. In the present contest, the chosen instruments should be correlated both with the price of cobalt and with the consumption of cobalt in the particular end use studied.

In the geometric lag specification two types of equations were estimated using different techniques.

The first type of equation had only the lagged price of cobalt as an explanatory variable in addition to the activity, substitute and lagged dependent variables. The estimation of such an equation is relatively simple because an instrumental variable technique is not required. The reason is that in the context of simultaneous equation systems lagged endogeneous variables are treated as exogeneous or predetermined variables. However, OLS technique is also unsatisfactory here because stock adjustment models have been found to have autocorrelated residuals, even though the specification discussed above gives a spherical disturbance term. Since it was not possible to treat satisfactorily a very general model of autocorrelation, it was decided to settle for a model with first-order autocorrelated disturbance term. Thus denoting the error term in (3) by u_t , and assuming that it enters additively, we assume

$$u_t = \rho u_{t-1} + e_t$$

where e_t has zero expectation and a variance-covariance matrix $\sigma^2 I$. Thus e_t is itself not autocorrelated ⁽¹⁾.

(1) If a Koyck distributed lag model had been used and a Koyck transformation employed to arrive at the estimating equation then the disturbance term would have been autocorrelated even if the initial disturbance term was independent.

Cochrane Orcutt technique by correcting for the autocorrelation would give consistent estimates of the coefficients. If error term is normally distributed, the estimates would also be maximum likelihood ⁽¹⁾.

It is worth noting that the autocorrelation correction would be required whatever the value of the Durbin Watson statistic because of the reason noted above and also because in the presence of lagged dependent variable Durbin Watson statistic is an unreliable indicator of first order autocorrelation. Another statistic, called the h-statistic computed from the estimate of autocorrelation coefficient is employed for regressions with lagged dependent variable to test the null hypothesis of zero autocorrelation. However, the computer programme available does not estimate the h-statistic.

In the second type of Koyck equation estimated, the current price of cobalt entered as an explanatory variable in addition to others. Here, the estimation technique is a bit more complicated because not only do we have a problem of simultaneity bias but there also exists the problem of autocorrelated errors. To get consistent estimates in this case requires the application of Fair's estimation method ⁽²⁾. This method requires that among the instruments chosen be the current values of all predetermined variables, values of all predetermined variables once lagged, lagged value of endogeneous variable appearing on the left hand side of the equation and once lagged values of all endogeneous variables appearing on the right hand side. It can be easily shown that the above estimation procedure will give consistent estimates of the relevant coefficients.

(1) For a similar technique employed see Fisher, Cootner and Bailey (1972).

(2) Fair (1970)

The instrumental variables used for estimating demand functions will be listed with the empirical presentation of each function. Lagged US government stocks of cobalt and US government net purchases of cobalt are two instruments common to all demand functions. The choice of these instruments is indicated by the critical role that these variables have played in influencing the price of cobalt besides the exogeneous occurrences. The other instruments were chosen on account of their strong correlation with the price of cobalt as well as with the consumption of cobalt in the particular end use studied.

2.4 Period of Estimation

Consumption data are available for most end uses from 1943 to 1978⁽¹⁾. However, 1947 was used as the starting point for most equations because of the 2nd World War and the resulting possible disruption in the consumption and price behaviour. For similar reasons the Korean War years 1951 and 1952 were eliminated in the estimation of most demand functions except for those where the number of variables was quite large so that more degrees of freedom were required. For some activity variables consistent data till 1978 was not available. For example, for jet engines no figures could be obtained for years after 1975. In the case of consumption of cobalt in magnets the data for the activity variable, production of radios and televisions sets, was missing for the years 1976 - 78. In cases where data was not available, such as those noted above, the equations were regressed only over those years for which data on all the variables was available ⁽²⁾.

(1) The data and the sources used are given in the appendix.

(2) This is a standard practice in most econometric studies where consistent sets of data are not available. For instance see Fisher, Cootner and Bailey, op. cit.

The remainder of this chapter analyses the demand for cobalt in superalloys, magnets, cutting and wear resistant alloys, welding and hardfacing rods, catalysts, salts and driers, other metallic uses, and other nonmetallic uses. The estimation procedures discussed above have been used in the estimation of the demand functions for each of these eight end use categories.

2.5 Estimation Results of Demand Functions

In 1968 the Bureau of Mines published a new end-use breakdown in its cobalt consumption table. Many of the new consumption categories were not comparable with the old ones and in some cases it was found that some of the old categories had been added together to give a new end use category for post 1968 period. In the following estimation sections the method used to get a consistent data set for the period 1947 - 78 will also be discussed.

2.5.1 Superalloys

Bureau of Mines started its listing of superalloys with the Minerals Yearbook, 1969. This issue and the subsequent ones present data only for the current years, thus giving no indication into end use classification alignment between 1969 and previous years. A careful examination of the figures reveals that the "high temperature high strength alloys" reported in the Mineral Yearbooks prior to 1968 are the "superalloys" reported in 1969 and the following years. The 1968 figure presents a problem because the Yearbook, 1968 lists neither of these two categories. However, its alloys" seems to be a combination of "high temperature, high strength alloys" and nonferrous alloys for 1967. The figure

for latter is 0.177 million lbs and figure for former is 3.447 million lbs⁽¹⁾. It is assumed that the 1968 quantity assigned "nonferrous" alloys is a similar combination. 1968 consumption for nonferrous alloys is estimated as the arithmetic average of the 1967 figure, 0.177 million lbs⁽²⁾ and 1969 figure, 0.660 million lbs⁽³⁾. The average figure, 0.419 million pounds is subtracted from 3.061 to arrive at an estimate of 2.642 million pounds for superalloys in 1968.

Equations for cobalt consumption in superalloys (CCSA) were estimated using the deflated price of cobalt (PC), an activity variable, a substitute variable (nickel) for cobalt and some dummies as independent variables. Equations were estimated with an "inverted-V" distribution and a geometric lag distribution for the price of cobalt variable. Two activity variables were tried, production of jet engines (YJET) and commercial jet deliveries (YJD). YJET is a better proxy because it is much more closely related to cobalt consumption in superalloys. However, it suffers from the shortcoming that it does not take into account the fact that larger jet engines require a greater quantity of superalloy. This problem can be circumvented if it is assumed that the proportion of large and small jet engines has remained the same over the estimation period. Also, since no data exist on the deflated value of production of jet engines there was no other suitable proxy variable available.

(1) See Minerals Yearbook (1967, p. 382 and 1968, p. 406)

(2) See Minerals Yearbook (1967, p. 382)

(3) See Minerals Yearbook (1969, p. 399)

Since the early 1970's gas turbines have been used in increasing numbers for power generation. To capture the effect of consumption of superalloys in turbines a dummy, TURB, was used. Other alternative variables such as the number of turbine operated plants and turbine capacity were available only for a very short period of time rendering impossible their inclusion in the regression⁽¹⁾. The turbine dummy had a value of 1 from 1953 - 1972 and increased linearly from 1972 - 1978. This implied that the upward shift occurred gradually from 1972 - 1978 with the relative degree of substitution being the same for each year of the period 1972 to 1978.

A dummy variable DS was included to measure the effect of replenishment of war depleted stocks of materials. This dummy had a value of 1 for the years 1954 and 1968. 1954 was the post Korean War year and 1968 was the period of Vietnam War.

Other dummies introduced were D41 to reflect the increase in superalloy consumption brought about by a rapid increase in civilian jet production from 1958 and D4, to test the hypothesis that a shift in demand function occurred after the Korean War as a result of research and development during the war. D41 had a value of 0 for the period 1947 - 1957 and a value of 1 for the period 1958 - 1978. The dummy variable D4 was defined to equal 1 from 1947 to 1950, and 0 from 1953 to 1978⁽²⁾.

(1) Data for these variables was available only for the period 1966 - 1976 from the 'Statistics of Privately Owned Electric Utility Companies'.

(2) D4 could be introduced only in the geometric lag equation for which the estimation period was 1948 - 1950 and 1953 - 1975. It could not be included for "inverted V" equations for which the estimation period ranged from 1953 to 1975. The data for the latter began from 1947, but the lags involved in the equation meant the loss of six years at the start of the time period.

The deflated current price of nickel (PN) and price of nickel lagged (PN1) were also included to capture the substitution possibilities between cobalt and nickel. Tables 2.1 and 2.2 below show the estimated equations for "inverted-V" and geometric lag distributions respectively.

In equations estimated using the instrumental variable technique, the standard small sample significance tests cannot be applied because small sample properties of test statistics in this technique are not known. However, a good rule of thumb is that a coefficient at least twice its asymptotic standard error indicates a statistically significant relationship. In table 2.1 the best equation estimated is 2.13⁽¹⁾. The Durbin-Watson statistic in this equation indicates the absence of first order autocorrelation. All the coefficients are twice as large as their asymptotic standard errors. The program used does not print R^2 or R^2 (C) but this is not a very serious problem because the objective is to estimate elasticities and not to explain as large a variation as possible in the consumption of cobalt. According to this equation, the long run elasticity with respect to price is 0.45615 but the short run elasticity is only (0.45615) (0.063) or 0.0287. It takes 6 years for the effects of a price change to work itself out. The elasticity with respect to the activity variable is 0.53725. The latter could be explained by the exclusion of a proper proxy variable to reflect the increasing use of cobalt in turbines for power generation.

(1) The similar equation estimated in linear form provided equally good results but 2.13 was chosen because the coefficients can be directly interpreted as elasticities. Furthermore elasticities calculated from linear forms are only approximate measures.

Table 2.1

Results of the "inverted-V" equation
(dependent variable natural logarithm of consumption of cobalt in superalloys), 1953 - 1975

	Equation	C	lnYJET	lnYJD	$\sum_{i=0}^6 w_i \ln PC_{t-i}$	lnTURB-	DS	D41	lnPN	lnPN1	DW
2.11	Basic equation	0.3259 (0.15456)	0.22913 (1.1897)		-1.375 (-2.542)	0.3585* (2.5714)	-0.3243 (-1.3226)	-0.54766 (-1.8685)	-1.0127 (-1.659)		1.5934
2.12	Dropped lnPN from 2.11	-0.8996 (-0.5165)	0.3428* (2.1153)		-1.00065* (-2.4595)	0.25355* (2.1048)	-0.3745 (-1.64)	-0.4483 (-1.7586)			1.8534
2.13	Dropped D41 from 2.12	-3.3897* (-3.4779)	0.53725* (4.6918)		-0.45615* (-2.31)	0.3323* (3.253)	-0.4442* (-2.144)				1.9847
2.14	lnPN1 in 2.13	-3.3716* (-3.096)	0.5306* (4.2015)		-0.394 (-1.6434)	0.3255* (2.581)	-0.4263 (-2.036)			0.04716 (0.081)	2.039
2.15	lnYJD activity variable in 2.13	1.3448 (1.2967)		0.0173 (0.1527)	-0.8558 (-1.1042)	0.2763* (2.58)	-0.1245 (-0.5903)		1.0047* (2.1618)		1.822

Notes: The figures in the parentheses are the ratios of the estimated coefficients to their asymptotic standard errors. An asterisk denotes that the coefficient is significant, that is, its estimate is at least twice the standard error.

Instrumental variables used are Government stocks lagged, (GS1) and net purchases for Government stocks (DGS).

The program used does not estimate R^2 and $R^2(C)$ for instrumental variable equations.

Table 2.2

Results of the Geometric Lag Equation (dependent Variable Consumption of Cobalt in Superalloys), 1948 - 1950, 1953 - 1975

Equation	C	PC1	PC	YJET	CCSA1	PN	DS	PN1	D4	D41	lnTURB	TURB	ρ	DW	R ²	R ² (C)
2.21 Basic equation	4.3296* (2.52)	-0.911* (-2.08)		0.003177* (4.353)	-0.62775* (-2.704)		-1.262* (-2.147)	0.7472 (0.7967)	-1.903* (-3.65)	-1.063 (-1.5784)	1.54* (4.357)		-0.46	2.23	0.722	0.574
2.22 TURB substitut- ed for lnTURB in 2.21	2.842 (1.584)	-0.8338* (-1.702)		0.000325* (3.9447)	-0.68795* (-2.57)		-1.295* (-2.02)	1.7176* (1.7374)	-1.824* (-3.096)	-1.0498 (-1.3847)		0.6238* (3.5946)	-0.388	2.09	0.677	0.5047
2.23 dropped PN1 from 2.21	5.042* (3.459)	-0.94599* (-2.2388)		0.000306* (4.3418)	-0.60067* (-2.6325)		-1.201* (-2.097)		-2.0336* (-4.243)	-1.0606 (-1.6317)	1.6577* (5.1695)		-0.509	2.257	0.711	0.5845
2.24 tried PN in- stead of PN1 in 2.21	5.1297* (2.88)	-0.924* (-1.99)		0.00029* (3.715)	-0.5699* (-2.297)	-0.152 (-0.182)	-1.106 (-1.763)		-1.875* (-3.23)	-1.034 (-1.457)	1.616* (4.5557)		-0.435	2.194	0.6161	0.397
2.25 dropped D41 from 2.23	2.75* (7.133)	-0.275 (-1.627)		0.000309* (4.3078)	-0.586* (2.5787)		-1.2909* (-2.229)		-1.60047* (-3.77)		1.4603* (4.5064)		-0.303	1.892	0.673	0.558
2.26 with PC instead of PC1. Estima- tion with Fair's method	1.93* (1.65)		-0.2164 (-0.7634)	0.000264* (3.0282)	-0.5294* (-1.9588)	0.3908 (0.354)	-1.085 (-1.599)		-1.258* (-1.763)			0.5312* (2.9134)	-0.944	1.722	--	--

Notes: An asterisk (*) denotes significance at the 5 percent level on a one-tail test.

R²(C) is R² corrected for degrees of freedom. ρ is the value of rho in the Cochrane - Orcutt technique to correct for first order autocorrelation.

The estimation period for all equations is 1948 - 1950 to 1953 - 1975 except for 2.26. For 2.26 the period is 1949 - 1950 to 1953 - 1975.

The price of nickel turns out to be insignificant. It was introduced as a current price variable, as a lagged variable and also with an inverted V distribution. The results with the latter were worse than with current price of nickel and price of nickel lagged. We have therefore not reported these results⁽¹⁾. This insignificance could be the result of the poor quality of the data or it could be that nickel is both a substitute and a complement for cobalt in this end use, and these effects offset each other.

The value of DS indicates that there was a significant downward shift in the demand function in the post Korean War year and in the year of the Vietnam War. The coefficient of DS, -0.4442 cannot be interpreted as a 44.4 percentage downward shift in the years 1954 and 1968. Halvorsen and Palmquist (1980) have pointed out the fallacy in assuming that the estimated coefficient of a dummy variable, multiplied by 100, is equal to the percentage effect of that variable on the variable being explained in semilogarithmic equations⁽²⁾.

This fallacy arises from treating the dummy variables on par with other explanatory variables without noting the fact that dummies are discontinuous variables whereas the others are continuous. They show that the percentage effect is equal to $100 \cdot [\exp(0.444) - 1]$. Thus, the downward shift in demand function for superalloys in 1954 and 1968 was 56 %.

The turbine dummy shows that the demand function for superalloys has been shifting upwards from 1972 to 1978. The coefficient of TURB, 0.332, could perhaps be interpreted as the elasticity of substitution for turbines.

(1) They are available from the author on request.

(2) See Halvorsen and Palmquist (1980)

In table 2.2, the best equation estimated is 2.23. All the coefficients except D41 are significant at the 5 percent level. However, by dropping D41, the lagged price of cobalt becomes insignificant and the R^2 , and R^2 adjusted both fall. The price of nickel is insignificant. Logarithm of the turbine dummy gives a better fit than the untransformed dummy. It is also worth noting that the coefficient of the lagged dependent variable is significant for all the regressions estimated.

At the point of means the short run elasticity (one period lagged) with respect to price of cobalt is 0.78803 and 0.492315 in the long run⁽¹⁾. The elasticity in the short run with respect to the activity variable is 0.79835 and in the long run is 0.49873⁽²⁾.

The geometric lag model therefore gives a short run elasticity greater than the long run elasticity. This result seems implausible for the cobalt market. Hence, for superalloys the estimated elasticities used would be those derived from the equation 2.13.

(1) Mean of cobalt price is 2.28334 and mean of the dependent variable is 2.74104. $1 - \mu$ is -0.60067, therefore μ is 1.60067. Since $\mu\beta$ for price of cobalt is 0.94599, β the long run effect is 0.591.

(2) Mean of YJET is 7146. $\mu\beta$, coefficient of YJET giving the short run effect of YJET is 0.000306 and β is 0.0001913.

2.5.2 Estimation of Demand Function for Cobalt in Magnets

Equations for cobalt consumption in magnets (CCM) were estimated using the price of cobalt, price of nickel as a substitute for cobalt, an activity variable and a dummy as independent variables. Equations were estimated with an "inverted-V" distribution and a geometric lag distribution for the price of cobalt variable. Two activity variables used in the regression were, production of radios and television sets (YTV) and personal consumption expenditure in constant dollars on radios, and televisions (DCERT). YTV has the advantage of including the stocks of radios and televisions as well as the total sales. However, it cannot capture the effect of large sets using stronger loudspeakers and therefore consuming more magnets. DCERT would incorporate the latter because expenditure incurred on larger sets would be proportionately more. Apriori, it was difficult to determine which of these two variables would capture better the consumption of cobalt in magnets.

A dummy variable DMA2 was included to reflect the substitution of ceramic magnets (using less cobalt) for Alnicos (using more cobalt). Ceramics were first introduced in 1953 so DMA2 had a value of 1.0 from 1947 - 1953 and it then increased linearly until 1964 at which time the substitution of ceramics for Alnicos ended. The dummy remained constant from 1964 - 1978. Rare earth magnets were discovered in 1974. It was, however, not certain whether commercial use of rare earth magnets had begun. A separate dummy as well as a reformulation of DMA2 were used to reflect the substitution in favour of rare earth magnets. However, both these attempts were unsuccessful.

The price of nickel was introduced both as a separate variable and in the form PC/PN. The ratio of the price of cobalt to the price of nickel was used as the price variable in the equation

because it was felt that substitution between cobalt and nickel in magnets depended on the relative prices of nickel and cobalt. The results from using the two activity variables are reported in table 2.3. Tables 2.4 and 2.5 give the regression estimates obtained by postulating a geometric lag and an "inverted-V" distribution respectively. In table 2.3, the equations 2.34 and 2.35 are superior to the other equations. However, for magnets the geometric lag equations 2.41 and 2.42 (table 2.4) are even better than equations 2.34 and 2.35 because besides including all the variables of these latter equations they also include the lagged effect of cobalt consumption in magnets and all the coefficients have much higher t-values. Equations 2.41 and 2.42 are quite close to each other in the value of the coefficients and their significance. However, equation 2.41 is slightly better in terms of the D-W statistic and t-values. Therefore the elasticities would be calculated using equation 2.41. The short run elasticity with respect to price is 0.02 and elasticity in the long run is 0.0322. The short run elasticity with respect to nickel is 0.8997 and the elasticity in the long run is 1.4533. The elasticity with respect to YTV in the short run is 0.936905 and 1.51338 in the long run⁽¹⁾.

The elasticity with respect to price of cobalt is smaller than expected but the elasticity with respect to the substitute variable nickel is quite high. This is to be expected for magnets where cobalt and nickel are fairly close substitutes. The elasticity of YTV is also close to 1 in both the short and the long run.

(1) All the elasticities have been calculated at the point of means. For the period 1953 to 1972 and 1976 to 1978 the mean price of cobalt is 2.24414, mean price of nickel is 0.900306, mean of YTV is 81.7304, mean of CCM is 2.72304. The procedure used is the same as that described above for superalloys.

Table 2.3

Dependent Variable Natural Logarithm / Untransformed Consumption of Cobalt in Magnets (lnCCM/CCM)

Equation	C	lnPC	lnDCERT	lnPN	lnYTV	lnRPCN	RPCN	DCERT	DMA2	DW	ρ	Regression Period
2.31 untransformed with DCERT	3.515* (5.078)						-0.3565* (-2.133)	0.1313* (3.527)	-0.1654 (-1.764)	1.48		1947 - 1950, 1953 - 1978
2.32 in logs with DCERT	0.793* (2.744)	-0.7387 (-1.633)	0.852* (2.418)	-1.237 (-1.44)					-0.1577* (-2.086)	1.8	0.223	1947 - 1950, 1953 - 1978
2.33 dropped lnPN from 2.32	1.004* (3.957)	-0.35 (-1.16)	0.447* (2.6477)						-0.0985 (-1.808)	1.828	0.19	1947 - 1950, 1953 - 1978
2.34 in logs with DCERT	1.076* (4.1)		0.4466* (4.26)			-0.3738* (-2)			-0.1055* (-2.59)	1.4		1947 - 1950, 1953 - 1978
2.35 in logs with YTV	-3.735* (-3.94)	-0.035 (-0.36)		1.08* (4.099)	1.256* (4.86)				-0.12974* (-4.138)	2.02		1953 - 1972, 1976 - 1978
2.36 in logs with YTV	-2.06 (-1.718)				0.7508* (2.345)	0.00033 (0.00249)			-0.0475 (-1.366)	0.92		1953 - 1972, 1976 - 1978

Notes: The instrumental variables used were index of production of defence and space equipment (YDSE), DGS and GSI.

Equations 2.32 and 2.33 were estimated using Fair's estimation technique because of the presence of autocorrelation in the original equations.

Table 2.4

(Dependent Variable, CCM, Period 1953 to 1972 and 1976 to 1978)

Equation	C	PC	PC1	PN	PN1	YTV	CCM1	DMA2	ρ	DW
2.41	-1.94* (-3.98)	-0.024 (-0.367)		2.72* (5.419)		0.0312* (5.508)	0.381* (3.516)	-0.27* (-5.035)	0.766	2.147
2.42	-0.9866* (-2.597)		-0.0707 (-0.604)		2.5217* (5.025)	0.023* (4.615)	0.28999* (2.089)	-0.2162* (-3.844)	0.6385	2.187

Table 2.45

Dependent Variable Logarithm of Consumption of Cobalt in Magnets (lnCCM), "Inverted-V" Distribution for PC

Equation	C	$\sum_{i=0}^3 w_3 \ln PC_{-1}$	$\sum_{i=0}^6 w_6 \ln PC_{-1}$	lnPN	lnDCERT	lnYTV	DMA2	DW
2.451 lnDCERT as an activity variable	1.199* (2.76)	-0.6526 (-1.29)		-0.5786 (-1.1457)	0.5389* (2.344)		-0.1336 (-1.714)	1.93
2.452 dropped lnPN from 2.51	1.5066* (3.14)	-0.74064 (-1.509)			0.46356* (2.674)		-0.14546 (-1.922)	1.82
2.453 $\sum_{i=0}^6 w_6 \ln PC_{-1}$ instead of $\sum_{i=0}^3 w_3 \ln PC_{-1}$ in 2.52	1.70 (1.386)		-0.8147 (-0.7405)		0.3886 (1.726)		-0.1448 (-0.98147)	1.77
2.454 lnYTV instead of lnDCERT in equation 2.51	-3.66768 (-4.2514)	-0.08159 (-0.44579)		1.10927 (3.9624)		1.25304 (5.238)	-0.133628 (-3.91108)	2.1575
2.455 $\sum_{i=0}^6 w_6 \ln PC_{-1}$ instead of $\sum_{i=0}^3 w_3 \ln PC_{-1}$ in 2.54			-0.1066 (-0.2503)	-1.1066* (-3.032)		1.266* (4.024)	-0.1395 (-1.97)	1.973

Notes:

The instrumental variables used have been YDSE, DGS, GS1.

2.5.3 Estimation of Demand Function for Cobalt in Tool Cutting and Wear-Resistant Alloys

Data on "Cemented Carbides" and "Other Cutting and wear-resistant materials" was available separately from 1953 to 1968 but from 1969 onwards, Bureau of Mines aggregated these two categories into one called "cutting and wear-resistant alloys". Hence the two data sets were added together from 1953 to 1968⁽¹⁾. The consistent set obtained for "cutting and wear resistant materials" was then added to "tool steel"⁽²⁾.

Equations for the demand for cobalt in cutting and wear resistant alloys (CWR) were estimated using the price of cobalt (PC), price of tungsten (PT) (as a substitute for cobalt in this end use), and index of production of nonelectrical machinery (NELM) as the dependent variables. Deflated value of shipments of small cutting tools (DSCT) was also used as an activity variable but the performance of NELM was superior to that of DSCT. All the equations estimated with DSCT had DW statistic below 1. In 1974, cutting and wear resistant alloys were being used in diverter valves. A dummy was introduced to capture this effect but the equations with the dummy had wrong signs and/or low t-values, so this dummy was discarded from all the regression equations estimated. Both linear and log-linear forms of the demand functions were estimated using current price of cobalt, price of cobalt with "inverted-V" lag structure and a geometric lag structure. However, none of the geometric lag equations were successful. All

(1) Before 1953, cutting and wear resistant alloys were included with superalloys. The backcasts of cemented carbides were obtained from Burrows before adding this category to other cutting and wear resistant materials for the period 1947 to 1953.

(2) Before 1969 "tool steel" was listed as "high speed steel".

the coefficients (except that of NELM) were well below twice the value of their asymptotic standard errors. Lagged and current prices of cobalt also had wrong signs. These equations were therefore not reported⁽¹⁾. Only the results of the former two are reported in table 2.5.

An examination of the equations reveals that the price of tungsten is insignificant in all the equations estimated. Also, *t* values in equation 2.53 (with *V* distribution for price of cobalt) and 2.55 (with current price of cobalt) go up significantly when tungsten is dropped as an explanatory variable⁽²⁾. The choice lies between equations 2.53 and 2.55⁽³⁾.

The Durbin-Watson statistic of 2.53 is better than that of 2.55. At the 5 percent level (with three explanatory variables) the hypothesis of no autocorrelation can be rejected for equation 2.53 but not for 2.55. The very low value of Durbin-Watson in 2.55 reflects substantial positive autocorrelation. This in turn means that the *t* values in 2.55 are artificially high. Moreover, for cutting and wear resistant alloys, as in the case of superalloys, one would not expect the effect to be instantaneous.

In equation 2.53 the elasticity with respect to price of cobalt in the short run is (0.6154) (0.063) or 0.03877, in the long run it is 0.6154. The activity elasticity is 0.9667 which does not differ significantly from 1.

(1) Any or all of the results of the geometric lag equations are available from the author on request.

(2) A two lag *V*-distribution for tungsten was also tried but this too did not change the insignificance of the coefficient of price of tungsten. See equation 2.56 in table 2.5.

(3) Equation 2.51 in untransformed variables is quite good but it has a lower D-W statistic than equation 2.53. Also the elasticities from 2.51 would have to be calculated at the means and therefore would only be approximate measures.

2.5.4 Estimation of Demand Function for Cobalt in Salts and Driers

In the econometric estimation of the demand for cobalt for salts and driers (CSD), crude-oil runs to refineries (YPET) and (deflated) value of shipments of paints, varnishes, and lacquers (DSP) were used as activity variables. The prices of molybdenum (PMO), nickel (PN), manganese (PMN), and lead (PL) were used as prices of substitutes and complements. A dummy variable DLEAD was introduced to test the effect of government regulation of the lead content in paints. The dummy had a value of 1 for the years 1947 - 1968 and a value of zero for the years 1968 - 1978. The sign of this dummy was expected to be positive because regulation probably increased cobalt consumption in this end use⁽¹⁾. Linear and log linear, geometric and inverted lags were tried for this end use like for all the others. The "inverted V" equations are reported in table 2.6. In equation 2.61 all the price variables and lnDSP are insignificant. Too many price variables can lead to the problem of multicollinearity and insignificance of the t values.

Thus, in equation 2.61 most of the price variables are dropped except for price of cobalt and price of lead. Lead was retained for it was felt that in salts and driers lead is a more important substitute for cobalt than molybdenum and nickel. A three year "inverted V" lag structure is tried in equations 2.61 and 2.62 but is unsuccessful. Therefore in equation 2.63 only the current price of lead is introduced as an explanatory variable. The current price of lead is significant and with the right sign but the "inverted V" three year lag structure for price of cobalt is still insignificant. A six year structure is tried in equation 2.64. The coefficient of this lag structure is closer

(1) See for details see Charles River Associate (1976)

Table 2.5

Dependent Variable Natural Logarithm / Untransformed Consumption of Cobalt in Cutting and Wear Resistent Alloys, $\ln CWR/CWR$

Equation	C	$\sum_{i=0}^6 w_6 PC_{-i}$	$\sum_{i=0}^6 w_6 \ln PC_{-i}$	$\ln PC$	$\ln DSCT$	NELM	$\ln NELM$	$\ln PT$	$\sum_{i=0}^2 w_2 \ln PT_{-i}$	DW	Period of Estimation
2.51 untransformed	0.8966 (1.462)	-0.398* (-2.097)				0.01527* (5.3436)				1.326	1953 - 1978
2.52 ln logs	-3.50* (-2.413)		-0.7096 (-1.778)				-0.95* (-3.145)	0.056* (0.2345)		1.538	1956 - 1977
2.53 dropped $\ln PT$ from 2.52	-3.596* (-4.642)		-0.6154* (-2.432)				-0.9667* (-6.78)			1.59	1953 - 1978
2.54 2.52 in cur- rent variables	-4.552* (-4.816)			-1.0216 (-1.905)			1.196* (5.732)	0.2274 (0.774)		1.408	1956 - 1977
2.55 dropped $\ln PT$ from 2.54	-4.3017* (-9.789)			-0.328 (-2.035)			1.081* (11.699)			1.298	1947 - 1950, 1953 - 1978
2.56 using $\sum_{i=0}^2 w_2 \ln PT_{-i}$ in 2.53	-7.8* (-2.866)		0.1375 (0.19)				1.957* (-3.227)		-1.1617 (-1.622)	1.18	1958 - 1977
2.57 using DSCT in- stead of NELM in 2.55	1.7846* (6.487)			-1.00766 (-3.89)	1.59* (6.6)					0.9	1947 - 1950, 1953 - 1978

Notes: The regression period for 2.52 and 2.54 is 1956 - 1977, because the data on tungsten is available only for this period.

The instrumental variables used are GSI, DGS, YDSE and index of production of electrical machinery (YELM).

Table 2.6

Dependent Variable Natural Logarithm of Consumption of Cobalt in Salts and Driers (lnCSD)

Equation	C	lnYPET	lnDSP	lnPC	DLEAD	$\sum_{i=0}^3 w_i \ln PC_{-i}$	$\sum_{i=0}^6 w_i \ln PC_{-i}$	$\sum_{i=0}^3 w_i \ln PL_{-i}$	lnPL	lnPMO	lnPN	DW	Period
2.61 Basic equation	-12.46* (- 6.278)	1.546* (5.782)	0.552 (1.548)		-0.3066* (-2.427)	-0.025 (-0.1786)		-0.0954 (-0.7165)		-0.1458 (-1.188)	-0.285 (-0.711)	1.907	1951 - 1978
2.63 dropped lnDSP, lnPMO, lnPN from 2.61	-12.56* (- 7.9)	1.62* (8.409)			-0.308* (-3.496)	-0.107 (-1.06)		-0.074 (-0.56)				1.8027	1951 - 1978
2.63 used lnPL in equation 2.62	-12.47* (- 8.76)	1.64 (9.637)			-0.308* (-3.94)	-0.115 (-1.25)			-0.1095* (-2.343)			2.14	1951 - 1978
2.64 used $\sum_{i=0}^6 w_i \ln PC_{-i}$ in 2.63	-11.02* (- 6.99)	1.4367* (7.842)			-0.346* (-4.411)		-0.1895 (-1.837)		-0.1013* (-2.206)			2.177	1953 - 1978
2.65 used lnPC in- stead of $\sum_{i=0}^6 \ln PC_{-i}$ in 2.64	- 7.9566* (- 6.248)	1.0578* (7.028)		0.0663 (0.6203)	-0.5055* (-5.62)				-0.074 (-1.14)			1.137	1947 - 1950 and 1953 - 1978

Notes:

The instrumental variables that have been used are GSI, DGS and Index of Industrial Production, YIP.

An asterisk denotes coefficients atleast twice as large as the asymptotic standard errors.

to twice the value of its standard error. The current price of cobalt is used in equation 2.65 but the results are poor as compared to those from equation 2.64. Price of cobalt is not only insignificant but also has the wrong sign. Moreover, the D-W statistic of equation 2.64 shows the presence of substantial first-order autocorrelation. Equations in linear form and with geometric lag structure did not give results as good as those with an "inverted-V lag" structure. These equations have therefore not been reported here.

In the best equation estimated (2.64) the short run price elasticity is (0.1895) (0.063) or 0.01194. The long run price elasticity is 0.1895. The elasticity with respect to the price of lead is 0.1013, and activity elasticity is 1.437.

2.5.5 Estimation of Demand Function for Catalysts

The category "catalyst" has been included in consumption of cobalt in "other nonmetallic uses" till 1966. From the year 1967 "catalyst" has been reported as a separate category under "chemical and ceramic uses". The consumption of cobalt in catalytic applications has exceeded four hundred million pounds in all years since 1967 with the exception of 1969. Since 1973 it has exceeded 1000 million pounds except for 1978 when consumption fell sharply to just a little over 400 million pounds. The exponential increase in consumption of cobalt as a catalyst warrants the estimation of a separate demand function for it.

The demand function for cobalt consumption in catalytic compounds was estimated using the price of cobalt, (PC), crude petroleum runs to refineries (YPET) and prices of molybdenum (PMO) and nickel (PN) as complement and substitute for cobalt

respectively. The equations were estimated using linear and log linear forms with "inverted-V" and geometric lag structures. None of the geometric lag structure equations were successful. The lagged consumption of cobalt was insignificant in all demand functions estimated. The results from using the "inverted-V" lag structure are given in table 2.7.

In table 2.7, prices of molybdenum and nickel are tried in equations 2.71 and 2.72, but the coefficients of both these variables are well below twice the value of their standard errors. These variables are therefore dropped in the subsequent three equations. The D-W statistic for 12 observations is not defined so it is difficult to know from the value of the D-W statistic if first order autocorrelation is present. However, for 15 observations (the minimum number for which the statistic is defined) the D-W statistic with two explanatory variables (excluding the constant term) must be at least 1.54 for the null hypothesis of zero first order autocorrelation to be accepted. Therefore using D-W as a criterion the best equation estimated is 2.74.

In equation 2.74, the short run effect of price is (7.91243) (0.063) or 0.4985 and the long run effect is 7.91243. The short run price elasticity evaluated at the point of means is 1.375, the elasticity in the long run is 21.82⁽¹⁾. The elasticity with respect to the activity variable is 15.6965⁽²⁾.

(1) Mean price of cobalt from 1967 to 1978 is 2.29552, mean of cobalt consumption in catalyst is 0.83225.

(2) Mean of YPET is 4458.52.

Table 2.7

Dependent Variable is Cobalt Consumption in Catalyst, CCA, Period of Estimation 1967 - 1978

Equation	C	YPET	PMO	PN	PC	$\sum_{i=0}^3 w_3 PC_{-1}$	$\sum_{i=0}^6 w_6 PC_{-1}$	DW
2.71 Basic equation	1.934 (1.1138)	0.001959* (2.9817)	-0.28678 (-0.87086)	-2.8716 (-1.5737)		-3.188* (-2.6047)		1.9005
2.72 with $\sum_{i=0}^6 w_6 PC_{-1}$ instead of $\sum_{i=0}^3 w_3 PC_{-1}$ in 2.71	4.811 (1.6787)	0.00296* (2.6134)	-0.30432 (-0.852)	-2.392 (-1.3066)			-7.41824 (-2.3752)	2.1464
2.73 dropped PMO and PN from 2.71	-0.539 (-0.7796)	0.001605* (3.112)				-2.88018* (-2.583)		1.503
2.74 dropped PMO and PN from 2.72	2.9435 (1.793)	0.00293* (2.748)					-7.91243* (-2.4664)	1.8876
2.75 with current price of cobalt	-1.89886* (-2.82)	0.0009* (4.222)			-0.5586* (-3.2569)			1.357

Notes:

An asterisk denotes coefficients atleast twice the size of their standard errors.

Instrumental variables used are GS1, DGS and YIP.

2.5.6 Estimation of Cobalt Consumption in Hardfacing Rods and Materials

Econometric estimates of the demand for cobalt in hardfacing rods and materials (CHF) were calculated using production of welding rods and electrodes (YW) and production of jet engines (YJET) as activity variables. The price variables used were the price of cobalt and the price of nickel. With the discovery of new welding processes such as electron beam welding the cobalt consumption in welding electrodes has declined. Welding Engineer reported that 1966 was a record year with the old standby welding processes competing against new processes⁽¹⁾. To reflect the reduction of cobalt contained in welding rods a dummy variable DHF was introduced. This dummy had a value of 0 for the period 1947 to 1967 and a value of 1 for the period after 1967. Linear and loglinear regressions were estimated. "Inverted-V" and geometric lag versions were also tried. The geometric lag regressions had very few significant coefficients. Also the loglinear regressions had generally a poorer Durbin-Watson statistic and more insignificant coefficients as compared to the linear regressions. In table 2.8 only the regressions in linear form with an "inverted-V" distribution have been reported.

In equation 2.81 the lag distribution of cobalt and price of nickel are insignificant. It was noted in the consumption section that in this end use there is no suitable metallic substitute for cobalt. For example, Burrows points out that within the group of cobalt-base alloys, the attempts at substitution of nickel and other metals has always resulted in lowering hot hardness⁽²⁾. Hence, the insignificance of the coefficient

(1) See Welding Engineer Annual Fact File (1967, p. 12).

(2) See Burrows (1971, p. 89).

Table 2.8

Dependent Variable is Cobalt Consumption in Hardfacing Rods and Materials (CHF), Period of Estimation 1953 - 1975

Equation	C	DHF	$\sum_{i=0}^6 w_6^6 PC_{-1}$	$\sum_{i=0}^3 w_3^3 PC_{-1}$	YW	YJET	PN	DW
2.81 basic equation	0.496 (1.163)	- 0.5467* (- 5.41)	-0.0825 (-1.59)		0.00115* (5.97)	0.00000809 (1.47)	-0.5548 (-1.516)	2.12
2.82 dropped PN from 2.81	-0.0078 (-0.0328)	- 0.6677* (-10.715)	-0.07434 (-1.3833)		0.001147* (5.65)	0.00001214* (2.395)		2.051
2.83 $\sum_{i=0}^3 w_3^3 PC_{-1}$ instead of $\sum_{i=0}^6 w_6^6 PC_{-1}$ in 2.82	-0.09676 (-0.526)	- 0.66425* (-10.27)		-0.06477 (-1.425)	0.00121* (6.739)	0.0000142* (2.56)		2.017

Notes:

An asterisk denotes coefficients atleast twice as large as their standard errors.

The instrumental variables used are GSl, DGS and index of production of electrical machinery (YEIM).

of price of nickel is not unexpected. In equation 2.82, the price of nickel is dropped as an explanatory variable. The significance of the dummy DHF and the activity variable YJET improves by a considerable margin. However, the price of cobalt is still below twice the value of its standard error. In equation 2.83, a three year "inverted-V" lag structure is tried. The regression output shows only a very slight increase of 0.0088 in the residual sum of squares whereas the D-W is closer to 2 and the coefficients are more significant. Hence equation 2.83 was chosen to be the best equation estimated. It should be pointed out here that the estimation period for equations 2.80 to 2.83 ends in 1975 like that for the demand function for superalloys. This was because the data for jet engines was available only upto 1975. Since data for all the other explanatory variables including production of welding electrodes was available upto 1978 attempts were made to extrapolate the data for production of jet engines for the period 1975 to 1978 ⁽¹⁾.

In equation 2.83 the long run effect of price is 0.06477, and the short run effect is (0.06477) (0.17) or 0.01101. The short run price elasticity calculated at the point of means is 0.0436, and the long run elasticity is 0.2565. The elasticity with respect to jet engines is 0.201775, and with respect to welding electrodes is 1.68385 ⁽²⁾.

-
- (1) Three regressions were run using YJET as the dependent variable and using production of aircrafts, commercial jet deliveries and time as explanatory variables. All three regressions were unsuccessful. F statistic, R-squared, R-squared corrected for degrees of freedom and t values were too low to justify using these regressions for extrapolation purposes.
- (2) Means of price of cobalt (PC), YJET, YW and CHF for the period 1953 to 1975 are 2.08925, 7480.65, 734.105 and 0.527565 respectively.

2.5.7 Econometric Estimation of Cobalt Consumption in Other Non-metallic Uses

Demand function for cobalt consumption in other nonmetallic uses was estimated for the period 1967 to 1978. This category includes all nonmetallic uses listed under "chemical and ceramic uses" in the Mineral Year Books excluding cobalt consumption in catalysts⁽¹⁾.

The activity variables tried in the estimation of this demand function were index of production of durable goods (YDUR) and index of industrial production (YIP). Linear demand functions estimated using "inverted-V" lag distribution were superior to loglinear demand functions and geometric lag versions. The results of linear demand function estimated using both the activity variables are reported in table 2.9. Since detailed information on consumption of cobalt in other nonmetallic uses is not available it was not possible to specify substitutes and complements for cobalt in this end-use category. Consumption equations were therefore estimated using only the price of cobalt for price variable.

In table 2.9 equation 2.94 with index of industrial production as the activity variable is the best equation estimated. The D-W statistic though not defined for 12 observations is above 1.54, the critical value for 15 observations. All the coefficients are larger than twice the value of their standard errors. The short run effect of price is (0.063) (1.08272) or 0.0682 and the long run effect is 1.0827 itself. The short run

(1) This category is defined somewhat differently from that of Burrows. Burrows' definition includes only "other nonmetallic uses" as listed in the Mineral Year Books 1947 through 1968. This category was fairly large for the period 1947 to 1968. However, in post 1968 period the "other nonmetallic" was very small. Some miscellaneous items comprising it from 1968 were listed separately under "chemical and ceramic uses". The "other nonmetallic" was by itself too small to justify running a separate demand function for it.

Table 2.9

Dependent Variable is Cobalt Consumption in other Nonmetallic Uses (CONM), Period of Estimation 1967 - 1978

Equation	C	$\sum_{i=0}^3 w_3 PC_{-i}$	$\sum_{i=0}^6 w_6 PC_{-i}$	YDUR	YIP	DW
2.91	0.5358 (1.783)	-0.65278* (-2.802)		0.01054 (1.928)		1.8674
2.92 using $\sum_{i=0}^6 w_6 PC_{-i}$ instead of $\sum_{i=0}^3 w_3 PC_{-i}$ in 2.91	0.9919* (3.793)		-0.767* (-2.922)	0.007986 (1.8158)		1.2914
2.93 using YIP instead of YDUR in 2.91	0.56697 (1.6428)	-0.841945* (-2.189)			0.013027 (1.62189)	1.891
2.94 using YIP instead of YDUR in 2.92	1.1117* (4.424)		-1.08272* (-2.82165)		0.0117033* (2.02737)	1.643

Notes:

An asterisk denotes coefficients atleast twice the size of their standard errors.

The instrumental variables used have been GSI and DGS.

elasticity is 0.3514, and the long run elasticity is 5.5788. The elasticity with respect to the activity variable YIP is 3.166⁽¹⁾.

2.5.8 Econometric Estimation of Cobalt Consumption in Other Metallic Uses

Econometric estimates of demand for cobalt in other metallic uses were made for the period 1960 to 1978. It appears that new reporting procedures were used by the BOM after 1959 so that the data before and after 1959 were not strictly comparable. This category is the sum of all the categories listed under "metallic uses" by the Mineral Year Books with the exception of those already included in the estimation of different end use demand functions, namely, superalloys, cutting and wear resistant materials⁽²⁾, hardfacing rods and materials, magnets. Carbon steel, mill products made from metal powder, cast irons and electric steel were excluded from our "other metallic" category because data for these have been withheld for most years in the period 1960 to 1978. For the years 1967 and 1968 the nonferrous alloy figures included in the "other metallic" category were not those reported by BOM in these years. It was noted in the section on estimation of demand function for superalloys that the reported category "nonferrous alloys" was in fact a sum of two categories, "high temperature" and "nonferrous alloys" for years 1967 and 1968. The estimates of superalloys

(1) The elasticities have been calculated at the point of means. For the period 1967 to 1978, the mean of the dependent variable, CONM, is 0.4455, mean price of cobalt is 2.29552 and mean index of industrial production is 120.517.

(2) The latter is a sum of other tool steel, high speed steel, cemented carbides, cutting and wear resisting materials for period through 1966, sum of high speed and tool steel, and tool cutting and wear resistant materials for 1967 to 1968, sum of tool steel and cutting and wear resistant materials for the period 1969 - 1972.

obtained were subtracted from the quoted nonferrous alloy figures 3,625 and 3,061 for these years to obtain the actual consumption of cobalt in nonferrous alloys.

The demand function for other metallic uses was run using price of cobalt, price of nickel, and index of industrial production. The geometric lag versions were unsuccessful. All the variables including lagged consumption of cobalt in other metallic uses were insignificant. The logarithmic regressions were better than the linear regressions estimated. The loglinear demand functions estimated are reported in table 2.10. The regression equation 2.101 in table 2.10 has a significant lag structure for the price of nickel variable. In equation 2.102 the lag structure is extended to allow for one more year for the effect of a price change in nickel to work itself out. This extension results in the insignificance of the lag structure. In equations 2.103 and 2.104 a six year instead of a three year "inverted-V" lag structure is tried for the price of cobalt variable. The six year lag structure is not as successful as a three year lag structure. It is worth noting that the D-W statistic of all four equations is very close to two, hence the hypothesis of zero autocorrelation cannot be rejected at the 0.05 level of significance. The best equation estimated in terms of t-values and the residual sum of squares seems to be equation 2.101.

In equation 2.101, the long run elasticity with respect to price of cobalt is 1.0727 and the short run elasticity is (1.07271) (0.17) or 0.18236. The long run elasticity with respect to price of nickel is 1.25948 and the short run elasticity is (1.25948) (0.25) or 0.31487. The elasticity with respect to the activity variable, YIP, is 1.19764, which is not significantly different from one.

Table 2.10

Dependent Variable is Logarithm of Cobalt Consumption in other Metallic Uses (lnCOM), Period of Estimation 1960 - 1978

Equation	C	$\sum_{i=0}^3 w_3 \ln PC_{-i}$	lnYIP	$\sum_{i=0}^2 w_2 \ln PN_{-i}$	$\sum_{i=0}^3 w_3 \ln PN_{-i}$	$\sum_{i=0}^6 w_6 \ln PC_{-i}$	DW
2.101	-4.47787* (-3.11087)	-1.07271* (-2.74166)	1.19764* (3.9978)	-1.25948* (-2.00275)			2.1062
2.102 tried $\sum_{i=0}^3 w_3 \ln PN_{-i}$ in 2.101	-4.52639* (-2.71628)	-0.972723* (-2.15872)	1.19137* (3.56746)		-1.33424 (-1.70787)		2.0124
2.103 tried $\sum_{i=0}^6 w_6 \ln PC_{-i}$ in 2.102	-2.29709 (-0.92665)		0.711018 (1.4933)		-0.992591 (-1.02687)	-0.941217 (-1.9273)	2.0077
2.104 tried $\sum_{i=0}^2 w_2 \ln PC_{-i}$ in 2.103	-2.2135 (-1.11026)		-0.7018 (1.8023)	-0.9597 (-1.26464)		-0.99019* (-2.3943)	2.0654

Notes:

An asterisk denotes coefficients twice as large as their standard errors.

The instrumental variables used have been GS1, DGS, NEIM and YEIM.

2.5.9 Estimation of an Aggregate Demand Function for USA

An aggregate demand function for the USA was estimated with price of cobalt, index of industrial production and a dummy D6 as independent variables. D6 was introduced to take into account the shift in magnetic demand induced by the introduction of ceramic magnets. The demand function was estimated in linear and loglinear form, with "inverted-V" and geometric lag distribution. In the geometric lag equations lagged value of US consumption was found to be insignificant. In none of the equations estimated was the price of cobalt significant. In almost all regressions, the coefficient was well below twice the value of its standard error. Also D6 was found to have a wrong sign in the equations. Price of nickel was also introduced as a substitute variable for cobalt. But this too was insignificant in both the current and the "inverted-V" form. Since none of the regressions estimated were statistically significant they have not been reported here⁽¹⁾.

2.6 Estimates of Elasticities

This chapter presented econometric estimates of the demand for cobalt in eight major end use categories, namely, superalloys, magnets, cutting and wear resistant alloys, salts and driers, catalysts, hardfacing rods and materials, other nonmetallic and other metallic applications. Total consumption of cobalt in these end uses in 1978 was 16,560,000 pounds (out of total consumption in 1978 of 19,814,000 pounds).

⁽¹⁾ However, they are available from the author on request.

In most of the demand functions estimated, the lagged effects of price changes on cobalt consumption were important. The short run elasticities of demand usually were lower than the long run elasticities. Table 2.11 gives the short run and long run elasticities with respect to price as well as their weighted averages. The weights used are the shares of each end use in the total 1978 consumption of all end uses for which demand functions were estimated.

Table 2.11

Estimated Short-Run and Long-Run Elasticities of Demand for Cobalt in the United States, by End Use

End Use	1978 Consumption (Thousands of Pounds)	Percent of Total Consumption of End Uses for which Elasticity Estimates were made	Estimated Short-Run Price Elasticity	Estimated Long-Run Price Elasticity
Superalloys	4,251	25.67	0.0287	0.45615
Magnets	3,752	22.657	0.02	0.0322
Cutting and Wear Resistant Alloys	1,962	11.85	0.03877	0.6154
Salts and Driers	4,073	24.60	0.01194	0.1895
Catalysts	405	2.45	1.375	21.82
Hardfacing Materials	668	4.034	0.0436	0.2565
Other Metallic	1,218	7.355	0.18236	1.0727
Other Nonmetallic	231	1.395	0.3514	5.5788
Total	16,560	100.0 ^a	0.073 ^b	0.945577 ^b

a Total adds to 100.01 because of rounding error.

b Weighted average of elasticities of individual end uses.

In table 2.11 the weighted averages of the short- and long-run price elasticities are 0.073 and 0.945577 respectively⁽¹⁾. Burrows notes that a weighted average of the elasticities estimated for each end use sector provides only a minimum estimate of the aggregate demand elasticity⁽²⁾. This is because it is difficult to measure technological change induced by price changes. Burrows cites the example of ceramic magnets introduced in 1953. The introduction of these magnets could have been influenced by the high prices of cobalt in the 1940s and the 1950s. Other important technological developments that could have influenced demand include the discovery of new applications for metallic cobalt and the consequent increases in consumption of cobalt in other metallic applications. In the field of hardfacing rods and electrodes the discovery of a new welding process induced a substantial decline in cobalt consumption in electrodes for welding purposes. It is not possible to obtain a precise estimate of the technological factor. According to Burrows, technological change if accounted for could increase elasticity by 0.5.

Elasticity estimates were also obtained with respect to the activity and substitute variables. The inclusion of the latter in many regressions gave insignificant results and therefore it had to be dropped in some of the final regression forms estimated. In the case of magnets and other metallic uses a significant lag structure for the substitute variable enabled the calculation of both long and short run substitute elasticities. For magnets, the geometric lag structure gave best results and for other metallic uses the "inverted-V" lag structure for nickel was significant and "better" as compared to the regression with only the current price of nickel as the explanatory variable. The estimated substitute elasticities are reported in table 2.12.

(1) It has been pointed out that interesting relationships exist between end use elasticities and factor price elasticities. However, to calculate factor price elasticities one needs factor shares in different end uses, and data on factor shares in end uses is not available.

(2) See Burrows (1971, p. 97)

Table 2.12

Estimated Substitute Elasticities of Demand for Cobalt in the United States, by End Use

End Use	Substitute	Estimated Substitute Elasticity in the Short Run	Estimated Substitute Elasticity in the Long Run
Superalloys	-	-	-
Magnets	Nickel	0.8997	1.4533
Cutting and Wear Resistant Alloys	-	-	-
Salts and Driers	Lead	0.10113	-
Catalyst	-	-	-
Hardfacing Rods and Materials	-	-	-
Other Metallic	Nickel	0.31487	1.25948
Other Nonmetallic	-	-	-

No other lag structure except that which was implicit in the geometric lag hypothesis was tried for the activity variable. This is because it was felt that "inverted-V" lag structures in all the activity and price variables would result in the loss of too many degrees of freedom, and an unnecessarily complicated regression relationship. The various activity variables and their elasticities with respect to their end use categories are reported in table 2.13.

In the next chapter the producer price behaviour of major cobalt producers is discussed.

Table 2.13

Estimated Activity Elasticities of Demand for Cobalt in the United States, by End Use

End Use	Activity Variable	Estimated Activity Elasticity in the Short Run	Estimated Activity Elasticity in the Long Run
Superalloys	Jet engine production		-
Magnets	Index of production of radios and TV sets	0.936905	1.51338
Cutting and Wear Resistant Alloys	Index of production of nonelectrical machinery	1.4370	-
Salts and Driers	Crude oil runs to the refineries	1.437	-
Catalyst	Crude oil runs to the refineries	15.6965	-
Hardfacing Rods and Materials	a) Jet engine production	0.201775	-
	b) Welding electrodes	1.68385	-
Other Metallic	Index of industrial production	1.19764	-
Other Nonmetallic	Index of industrial production	3.1660	-

III PRODUCER PRICE BEHAVIOUR

3.1 Production Shares

In the first chapter it was pointed out that the supply of cobalt in the market was dominated by a small number of producers, with Zaire accounting for a substantial percentage. The table 3.1 below shows the approximate percentage share of producers in the noncommunist world (excluding Zaire) and Zaire in the total production of cobalt for the period 1972 to 1978.

Table 3.1

Shares of noncommunist producers (excluding Zaire) and Zaire as a percentage of total production

Year	Noncommunist	Zaire
1972	35.7	64.28
1973	38.76	61.23
1974	34.8	65.19
1975	47.0	53.02
1976	53.0	47.125
1977	60.5	39.49
1978	54.7	45.28

Notes:

Total noncommunist production is a sum of Australian, Botswana, Canadian, New Caledonian, Moroccan, Phillipine mine production and Finnish, German (West), US, Zaire, and Zambian metal production.

Table 3.1 shows that until 1972 Zaire accounted for nearly two thirds of the total output of cobalt in the noncommunist world. However, since 1972 the share of Zaire has been falling and in 1978 Zaire's output was only a little less than half of total production. Canada, Australia, Morocco, New Caledonia and Zambia together in 1978 accounted for nearly 45 % of the total world production. It is clear from these figures that the cobalt market is characterized by a high degree of concentration in production. This could be a result of several factors including the scarcity of readily exploitable reserves of cobalt, the vertical integration of producers, the relatively small amounts of cobalt that can be recovered from secondary sources and also due to the fact that the supply from other producers is mainly a by-product of other mining activities. The scarcity of reserves and the small quantities recovered from secondary sources is evident from the tables 1.4 and 1.3 respectively. Moreover, according to Burrows all major producers are integrated at least to the cobalt metal stage⁽¹⁾. A new producer must either refine his own cobalt or sell it to an established producer. Own refining tends to be costly and hazardous.

Given these conditions of supply in the cobalt market two hypothesis have been advanced concerning the behaviour of Zaire. First is that Zaire maximizes its own profits given the output of the smaller firms and the second is that Zaire cooperates with other producers in setting the price and therefore maximises joint profits⁽²⁾.

(1) See Burrows (1971, p. 115)

(2) See Burrows (1971, p. 116) and Charles River Associates (1976)

The first hypothesis seems to be quite plausible for the period upto 1972 when Zaire's share was significant in the total supply. However, the recent decline in Zaire's share makes it quite likely that the second hypothesis more accurately reflects the current producer price behaviour. The econometric results presented later in this chapter support the hypothesis of a cartellized behaviour in price setting.

The sections 3.2 and 3.3 discuss briefly the implications for price determination of these two hypothesis. For each hypothesis, two price determination models are developed. One model assumes that the demand function faced by the price setter is linear and the other assumes that the demand function faced is loglinear. Section 3.4 discusses the estimation techniques and proxies used and section 3.5 presents the empirical results and their analyses.

3.2 Linear Demand Function

3.2.1 Cartel Case

Total demand for cobalt Q is a sum of total noncommunist consumption D and net US government additions to stock of cobalt, X .

Total profits are:

$$\pi = P \cdot Q - C$$

where π represents profits, C is total cost and $P \cdot Q$ is total revenue.

Given that $Q = D + X$ and $C = f(Q)$ with $f'(Q) > 0$

$$\pi = P(D + X) - f(Q).$$

If D is linear in price (P) and activity variable (Y) then

$$\pi = P(a + bP + cY + X) - f(Q)$$

$$\pi = aP + bP^2 + cYP + XP - f(Q).$$

Maximizing profits with respect to Q and setting the result equal to zero gives:

$$\frac{\partial \pi}{\partial Q} = a \frac{\partial P}{\partial Q} + 2bP \frac{\partial P}{\partial Q} + cY \frac{\partial P}{\partial Q} + X \frac{\partial P}{\partial Q} - f'(Q) = 0.$$

$$\text{Since } \frac{\partial P}{\partial Q} = \frac{1}{b} \text{ and } f'(Q) = K^{(1)}$$

$$0 = \frac{a}{b} + 2P + \frac{c}{b}Y + \frac{X}{b} - K \quad (3.210)$$

$$0 = a + 2Pb + cY + X - Kb$$

$$0 = (D + X) + Pb - Kb$$

$$0 = \frac{D + X}{b} + P - K$$

$$P = K - \left(\frac{D + X}{b}\right) \quad (3.211)$$

We have derived the equation 3.211 in money terms. To estimate 3.211 in real terms the profit maximizing equation 3.210 would have to be rewritten in real terms as follows⁽²⁾:

$$0 = \frac{\partial \pi}{\partial Q} = a \frac{P^*}{b} + 2P + cY \frac{P^*}{b} + X \frac{P^*}{b} - KP^{**} \quad (3.212)$$

where P^* is the demand deflator and P^{**} is an index of factor prices and K now is the real marginal cost of production⁽³⁾. Solving 3.212 gives:

$$\frac{P}{P^*} = K \frac{P^{**}}{P^*} - \left(\frac{D + X}{b}\right)$$

(1) The primary method employed in mining cobalt is open pit mining. This is a relatively capital-intensive process, with short-run marginal cost fairly constant over a range of outputs. Transport costs in the short run could also be assumed to be relatively constant. Hence, it is quite reasonable to assume that marginal cost of extracting ore is constant at least in the short run.

(2) $Q = a + b \frac{P}{P^*} + cY + X$
and $\frac{\partial P}{\partial Q} = \frac{P^*}{b}$

(3) If MC in real terms is constant, in money terms MC is a function of factor prices.

Since no information is available on P^{**} it is assumed that $P^{**}/P^* = 1$ and therefore the estimate of MC obtained from the estimate of the constant term in the regression equations for linear demand need not be adjusted.

3.2.2 Own Profit Maximization by Zaire

Here, Zaire is assumed to set the profit maximizing price, given the net demand supplied by Zaire defined to be

$$Q = D + X - Z$$

where Z is the production of other firms. Solving as before for the profit maximizing price gives

$$\frac{P}{P^*} = K - \frac{D}{b} - \frac{X}{b} + \frac{Z}{b} \quad (3.221)$$

3.3 Loglinear Demand Function

3.31 Cartel Case

In this case price is set to maximize industry profits.

$$Q = D + X$$

$$D = AP^{\alpha}Y^{\beta}$$

$$Q = AP^{\alpha}Y^{\beta} + X$$

$$\pi = P \cdot Q - C$$

Differentiating π with respect to Q and setting the result equal to zero gives

$$P = K \left(\frac{\alpha D}{\alpha D + Q} \right) \quad (3.311)$$

Equation 3.311 can be rewritten as

$$\frac{1}{P} = \frac{1}{K} \left(\frac{\alpha D + Q}{\alpha D} \right)$$

$$\frac{1}{P} = \frac{1}{K} \left(1 + \frac{Q}{\alpha D} \right)$$

$$\frac{1}{P} = \frac{1}{K} + \frac{1}{\alpha K} \left(\frac{Q}{D} \right) \quad (3.312)$$

In equation 3.312 the inverse of the estimate of the constant term will give the estimate of MC and the inverse of the coefficient of Q/D will give the product of the MC and the elasticity of demand, α .

In equation 3.312 Q is the sum of D and X. If government demand is weighted differently by the price setter than noncommunist consumption, D, then 3.312 will have to be reformulated as

$$\frac{1}{P} = \frac{1}{K} + \frac{1}{\alpha K} \left(\frac{D + \theta_1 X}{D} \right) + u$$

$$\frac{1}{P} = \left(\frac{1}{K} + \frac{1}{\alpha K} \right) + \frac{\theta_1}{\alpha K} \left(\frac{X}{D} \right) + u \quad (3.313)$$

Equation 3.313 creates an estimation problem which will be discussed in the section on empirical results.

3.3.2 Own Profit Maximization by Zaire

If Zaire sets the price so as to maximize its own profits then Q would be defined as net demand supplied by Zaire with D being nonlinear in form.

$$Q = AP^{\alpha} Y^{\beta} + X - Z$$

where Z is the production supplied by other firms. Deriving the profit-maximizing price as before gives:

$$\frac{1}{P} = \frac{1}{K} + \frac{1}{\alpha K} \left(\frac{D + X}{D} \right) - \frac{1}{\alpha K} \left(\frac{Z}{D} \right) \quad (3.321)$$

The deflator for the loglinear demand case can be derived using the procedure similar to that used in section 3.2. Here, the demand function in real terms would be written as

$$Q = A \left(\frac{P}{P^*} \right)^{\alpha} Y^{\beta} + X$$

Maximizing profits as before gives

$$\frac{P}{P^{**}} = K \left(\frac{\alpha D}{\alpha D + Q} \right) \quad (3.322)$$

The deflator in the loglinear case is P^{**} , the index of factor prices. In this study P^{**} has been proxied by P^* since no information exists on P^{**} .

3.4 Estimation Technique and Proxies

The estimation procedure used is the instrumental variable technique. This technique is chosen on account of the assumptions made about the model. It is assumed that the producers set the price given expected demand (\hat{Q}). \hat{Q} would differ from Q as a result of random disturbances and forecasting errors. We would thus have a situation similar to that arising from 'errors in variables' in regression analysis, with the dependent variable being correlated with the error term. Use of ordinary least squares in this case would yield biased estimates of the coefficients. The instrumental variables used in estimating the price equation were, net US government purchases of cobalt (DGS), lagged government stocks of cobalt (GS1), deflated price of nickel (PN), index of production of electrical machinery (YELM), index of production of nonelectrical machinery (NELM) and index of production of defence and space equipment (YDSE).

The proxies used for the variables in the four formulations discussed above were as follows:

1. World deflated price of cobalt (P/P^*)

This was defined to be $PBDW = PC / [0.2901681 (PMM/1.167) + 0.7098319 (WPMCCC)]$ where PC is the price of cobalt in current dollars, PMM is the wholesale price index of metal and products and $WPMCCC$ is the weighted wholesale price index of major cobalt consuming countries. It is calculated as⁽¹⁾:

⁽¹⁾ For a similar technique used see Charles River Associates (1976).

$$\begin{aligned} \text{WPMCCC} = & (7.81) (\text{IEUB}) \text{WPB} + (4.63) (\text{IEUC}) \text{WPC} + (10.71) \\ & (\text{IEUU}) \text{WPUK} + (9.68) (\text{IEUF}) \text{WPF} + (18.29) (\text{IEUG}) \\ & \text{WPG} + (7.51) (\text{IEUI}) \text{WPI} + (39.24) (\text{IEUJ}) \text{WPJ} + \\ & (2.13) (\text{IEUN}) \text{WPN}. \end{aligned}$$

Where

IEUB is the US Belgium exchange rate index,
IEUC is the US-Canadian exchange rate index,
IEUU is the US-UK exchange rate index,
IEUF is the US-French exchange rate index,
IEUG is the US-German exchange rate index,
IEUI is the US-Italian exchange rate index,
IEUJ is the US-Japanese exchange rate index,
IEUN is the US-Netherlands exchange rate index.

Similarly, WPB, WPC, WPUK, WPF, WPG, WPI, WPJ, WPN are the wholesale price indices of the above countries listed in the same order. The exchange rate indices have been calculated by dividing each exchange rate expressed in dollars per unit of currency by the exchange rate prevailing for that currency in 1970 so that all the exchange rate indices have a base of 1970 = 1.

2. Supply by other firms (Z)

This has been calculated by subtracting net US government purchases of cobalt (DGS) from total production excluding Zaire (QBZAI). Total production excluding Zaire is world production (QBW) (calculated in the way shown in table 3.2) minus Zaire's production.

3. Noncommunist consumption (D)

This is a sum of total noncommunist consumption excluding USA (CBWX), and the consumption of USA (CUST). Another proxy for noncommunist consumption, TNCC, besides CBWX was also used.

The estimate of CBWX was obtained by taking world production in the noncommunist countries (QBW) for the period 1947 - 1978 and subtracting US consumption (CUST) and net additions to government stocks (DGS) from it⁽¹⁾. The estimate of TNCC was obtained by adding the cobalt consumption in all the noncommunist countries in the world for the period 1966 - 1976⁽²⁾.

4. Exogenous consumption (X)

Net US government purchases of cobalt (DGS) were assumed to be the only exogeneous source of demand for cobalt.

3.5 Empirical Results

3.5.1 Preliminary Discussion

The following versions of the linear demand and cartel case were tried.

- a) Assumed that there was no exogenous consumption X so that price was a function only of D

$$P = K - \frac{D}{b} \quad (3.511)$$

- b) The cartel reacts equally to changes in world consumption D and net US government purchases (DGS). In this case the regression was run on a new dependent variable (Q) which was the sum of D and DGS

$$P = K - \frac{Q}{b} \quad (3.512)$$

(1) Estimation of QBW was carried out using the same technique as that used in the construction of table 3.1

(2) Data for cobalt consumption in individual countries was available from the report published in 1978 by the Federal Institute for Earth Sciences Raw Materials and the German Institute for Economic Research.

- c) The cartel reacts differently to changes in D and DGS.
Here the regression was run on two dependent variables,
D and DGS.

$$P = K - \frac{D}{b} - \frac{X}{b} \quad (3.513)$$

The versions of the linear demand and own profit maximization tried were:

- a) Assumed no exogenous source of demand, so the dependent variables were Z and D.
- b) Assumed an exogenous source of demand, so the dependent variables were Z, D and X.

Versions tried of the loglinear demand and cartel case:

- a) Dependent variable was Q/D.
- b) This was equivalent to equation 3.313 derived earlier, where government demand was weighted differently by the price setter than D, so that the dependent variable was X/D, or (DGS/D).

Versions tried of the loglinear demand and own profit maximization.

- a) No exogenous source of supply so that equation 3.321 had only Z/D as the dependent variable. In this version, Z/D was replaced by a three year weighted average of the net exogenous supply consumption ratio with the weights approximating a negative exponential curve. Z/D without weights was also tried.
- b) Two dependent variables were used, Q/D and Z/D as in equation 3.321.

- c) Here it was assumed as in linear demand and cartel that producer weights differently changes in D and changes in X or DGS in setting the price so that the dependent variables became DGS/D and Z/D .

In all of the above equations three dummies were tried, $D6$, $D7$ and $D8$. $D6$ was introduced to reflect the change in magnetic demand that occurred when ceramics were introduced in 1957. $D6$ had a value of 1 for the years 1947 - 1956, and 0 for years 1957 to 1978. $D7$ was included to reflect changes in Zaire. The contractual arrangements under which cobalt is produced in Congo were drastically changed after 1966. The Congolese government expropriated the UMHK properties. Also political and social changes occurred in Congo which interfered with normal production so that price could have increased above its normal level. $D7$ had a value of 1 for the years 1947 - 1966 and a value of 0 for the years 1967 - 1978. Another dummy $D8$ was introduced to take account of the exceptional conditions of the year 1978. There was insurgence activity in Zaire and disruption in the supply of cobalt. In fact for two to four weeks there was a total stoppage in the supply from Zaire. Demand was exceedingly high with supply of cobalt not matching with the demand for it. There was an emergence of the so called 'grey' market for cobalt with price at one point exceeding \$ 40/pound¹. $D8$ had a value of zero for the years 1947 to 1977 and a value of one for the year 1978.

3.5.2 Results

The criteria used for choosing between different regressions were DW statistic, significance values, signs of the coefficients, a priori expectation of the size of MC, the plots of the actual

(1) See Metal Statistics (1979)

and fitted values, and Root mean squared error percent (RMSE %) of the predicted values⁽¹⁾. The best model chosen was required to have a DW statistic reasonably close to two, t values atleast twice as large as the asymptotic standard errors, and an estimate of MC lower than the smallest deflated value of price of cobalt, because price cannot be less than MC. With regard to plots, the fitted values should 'predict' the turning points in the actual values, and should have the same long run trend as the actual values. Since the ultimate objective is to simulate it is also desirable that the producer price behaviour equation chosen accurately model the actual behaviour of prices in the sense that the ex post forecasting error as measured by the root mean squared percent error be as small as possible.

None of the equations with the underlying hypothesis of 'own profit maximization by Zaire' were successful. The equations had wrong signs and/or low t values and poor D-W statistic, in some cases below 1. These equations, however, perform very well for the period upto 1974^(2,3). This suggests that though support maybe found for own profit maximization hypothesis for the period upto 1974 the same hypothesis cannot be accepted as representative of present producer price behaviour. The figures given in table 3.1 and the results obtained from regression analysis support the hypothesis of a cartellized behaviour on the part of major producers of cobalt. The table 3.3 gives the regression results of cartel case under the

(1) RMSE % is defined as $(\sqrt{\frac{1}{T} \sum \left(\frac{F - A}{A}\right)^2}) 100$.

See Pindyck and Rubinfeld (1976, p. 316).

(2) See equations 3.26 to 3.28 in table 3.2.

(3) Equations for the period 1953 - 1978 are reported in table 3.2.

Table 3.2

Own Profit Maximization by Zaire, Period of Estimation 1953 - 1978

Equation	C	QBXCW = X/D	X	D	Q/D	M	DGS	ERR	D6	D7	D8	Dependent Variable	Form	DW
3.21	0.4077* (9.68)	0.3274* (2.75)							0.0872 (-1.7214)	-0.1033* (-4.018)	-0.278* (-5.855)	1/PBDW	Loglinear demand	1.04
3.22	2.18* (4.89)		0.0133 (0.3005)	-0.012267 (-0.38718)					1.2742* (5.77)	0.32674 (1.496)	2.6818* (9.95)	PBDW	Linear demand	0.97
3.23	1.1078* (9.11)				-0.384* (-5.85)				-0.21277* (-6.3858)	-0.11315* (-8.676)	-0.186 (-6.52)	1/PBDW	Loglinear demand with govern- ment pur- chases in- cluded	2.13
3.24	0.724* (12.46)	-0.40072* (-2.903)				-0.384* (-5.85)			-0.2127* (-6.386)	-0.11315* (-8.676)	-0.1864* (-6.52)	1/PBDW	Loglinear demand	2.14
3.25	1.38* (6.72)		0.01245 (1.053)	0.00797 (0.824)			0.0584* (7.238)		1.1053* (11.537)	0.3865* (3.42)	2.16* (13.35)	PBDW	Linear demand	1.9
3.26 same as 3.21 but sample different	0.2786* (21.4)							0.3062* (8.078)	-0.04* (-2.25)	-0.06* (-7.74)		1/PBDW	Loglinear demand	1.79
3.27 same as 3.22 but sample different	0.36* (15.18)		0.0112* (4.86)	-0.00338* (-2.34)					-0.06* (-3.47)	-0.08* (-5.02)		1/PBDW	Linear demand	1.71
3.28 same as 3.25 but sample different	0.5* (5.6)		-0.009 (-0.73)	0.00109 (0.342)			-0.014 (-1.718)		-0.172 (-2.43)	-0.096* (-3.412)		1/PBDW	Linear demand	1.8

Notes: The instrumental variables used have been PN, YDSE, YELM, NEIM.

Estimation period of equations 3.26 to 3.28 is 1953 - 1974.

assumptions of linear and loglinear world demand. Equation 3.31 can be rejected on the grounds of wrong sign and a low t value of D as well as a very poor DW statistic. The best form estimated of version b) is equation 3.34. However, this equation has a coefficient of Q which is less than twice the value of its asymptotic standard error. But the plot of actual and fitted values of this equation in graph 1 is quite good. The long term trend of the predicted values is the same as that of the actual values. The turning points in the actual series, however, are predicted in some cases after a lag of one period. This is true especially for the years 1958, 1964, 1970, 1974. In six years, 1954, 1959, 1960, 1967, 1976, 1977, the absolute difference between the actual and predicted values is approximately \$ 0.255 per pound. The RMSE % of forecasts is 26.23 %⁽¹⁾. The RMSE % of this model is quite high so this model is rejected.

Equation 3.35 is superior to equation 3.34 in terms of the DW statistic, and significance of coefficients. The major turning points are predicted well by equation 3.35 but not the smaller upswings and downswings (see graph 2). The fitted values follow closely the long term trend of the actual values. For 5 years, 1958, 1960, 1971, 1975 and 1976, the absolute deviation between the actual and predicted price is on the average about \$ 0.228/pound. The RMSE % of the predicted values of this equation is 5.15 %. The estimate of MC is \$ 1.26276. This is well below \$ 1.7377, the upper bound for MC.

(1) In using Fair's estimation an additional observation at the beginning of the period is lost so the RMSE % was calculated from actual and fitted values for the period 1954 to 1978.

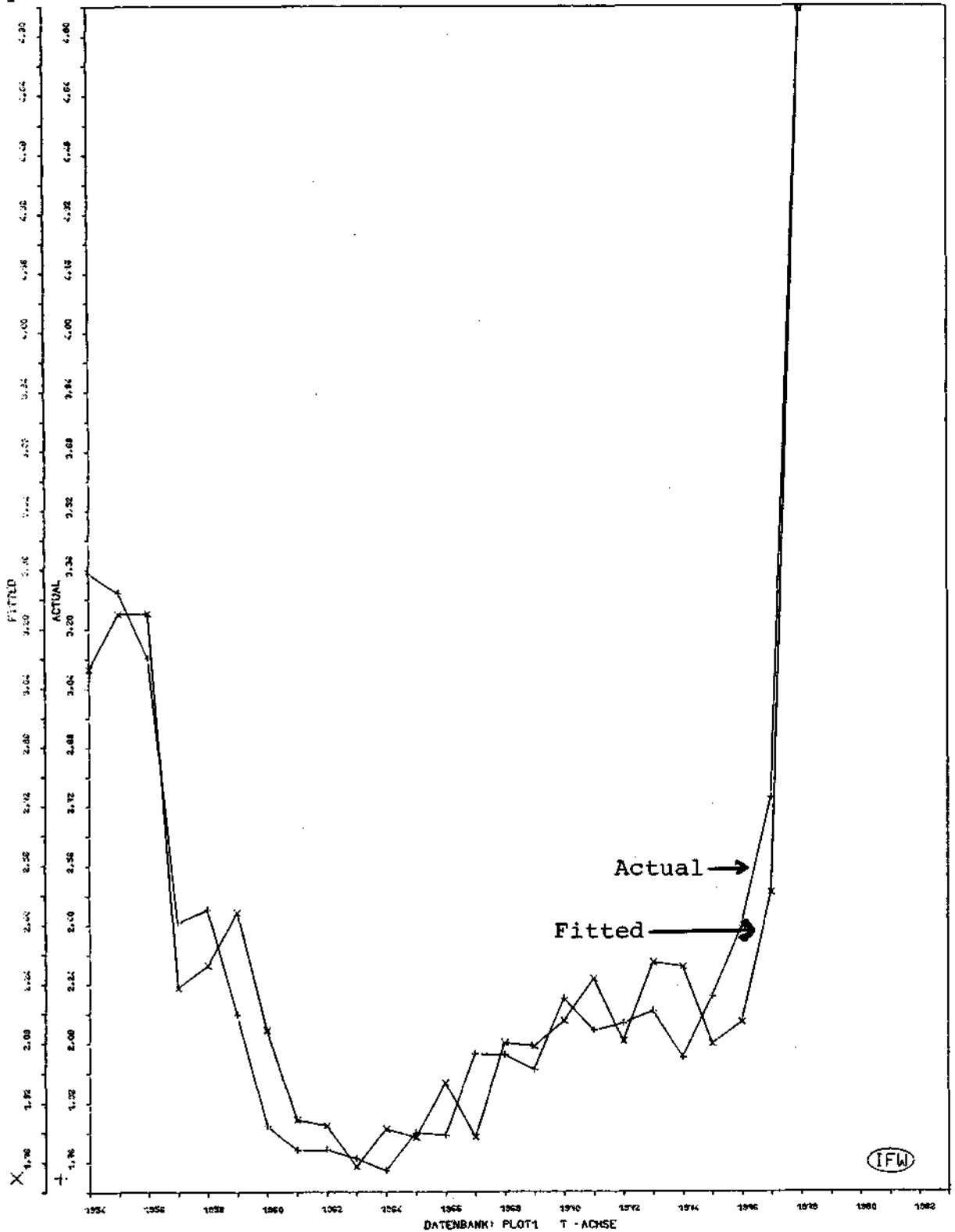
Table 3.3

Dependent Variable PBDW for Linear Demand and Cartel, PBDWI (inverse of PBDW) for Loglinear Demand and Cartel, Period of Estimation 1953 - 1978

Hypothesis	C	D6	D7	D8	Q/D	DGS/D	DGS	Q	D		DW
3.31 linear demand and cartel version a)	2.05016* (9.46407)	1.22662* (7.99382)	0.301394 (1.50116)	2.71007* (10.7759)					-0.002987 (-0.421169)		0.9684
3.32 same as 3.31 with version b)	1.44388* (4.75926)	1.31854* (9.31678)	-0.014507 (-0.08503)	2.42009* (8.563)				0.015933 (1.7673)			1.1008
3.33 dropped D7 in 3.32	1.469* (6.721)	1.31656* (9.55319)		2.43212* (9.3034)				0.0151249* (2.889)			1.0937
3.34 corrected for DW in 3.33	1.49411* (3.04368)	0.824654* (3.49636)		2.08408* (10.2824)				0.0158946 (1.54228)		0.8	1.5783
3.35 same as 3.31 with version c)	1.26276* (6.5595)	1.06275* (10.7447)	0.36063* (2.8908)	2.1892* (12.07)			0.057934* (6.32556)		0.016575* (2.935)		1.8077
3.36 loglinear demand and cartel, version a)	0.769445* (19.415)	-0.12927* (-6.7058)	-0.11932* (-8.091)	-0.23295* (-8.5902)	-0.212167* (-6.512)						1.41
3.37 same as 3.36 with version b)	0.55728* (54.405)	-0.12927* (-6.706)	-0.11933* (-8.091)	-0.23295* (-8.5902)		-0.21217* (-6.5121)					1.41

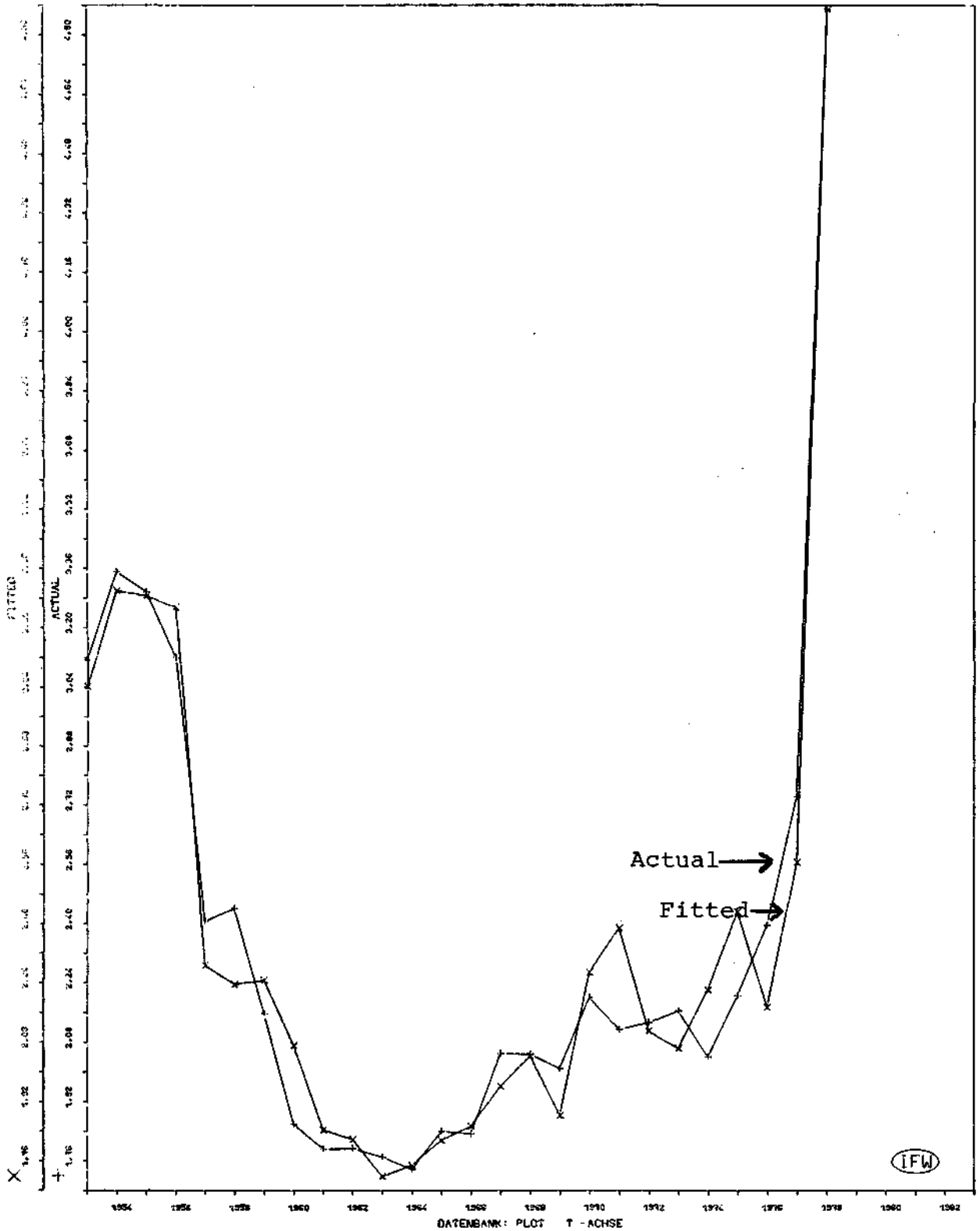
Graph 1

Actual Price Versus Predicted (Fitted) Price for
Equation (3.34), 1954 - 1978 (Dollars per Pound)



Graph 2

Actual Price Versus Predicted (Fitted) Price for
Equation (3.35), 1953 - 1978 (Dollars per Pound)

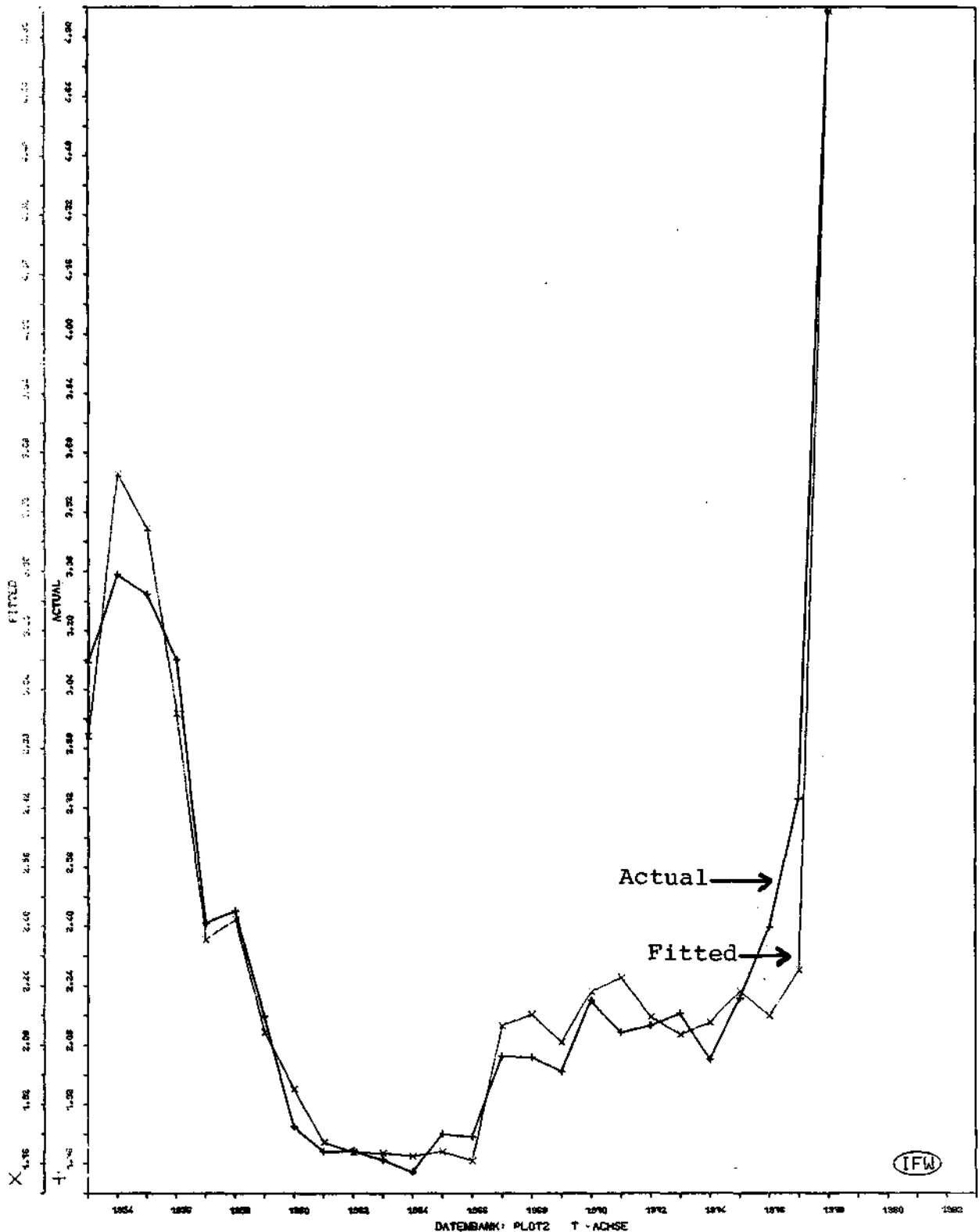


Equation 3.37 has very significant coefficients. The DW is in the inconclusive range for 5 % level but rejects the hypothesis of no autocorrelation at the 1 % level. This equation has an estimation problem which is one of under identification. The estimate of the constant term is $\frac{1}{K} + \frac{1}{\alpha K}$ where K is the MC and α is the elasticity of demand. The coefficient of DGS/D is $\theta_1/\alpha K$ where θ_1 is the estimate of the coefficient of the ratio of net government purchases of cobalt to noncommunist consumption. The regression equation gives us the estimates of two parameters but we need to calculate values of 3 coefficients. The estimates of two of the structural parameters (α , θ_1 , K) can be obtained only if one of them is known in advance. Since we desire estimates of α and K, θ_1 would have to be specified apriori. We obtained the estimate of θ_1 by taking the ratio of the coefficients of DGS and D in equation 3.35, which is 3.5. Then given that $\frac{1}{K} + \frac{1}{\alpha K}$ is 0.557278 and $\frac{\theta_1}{\alpha K}$ is 0.212167, we get 2.01345 as the value of K. This estimate of K is greater than the maximum acceptable value of K. Therefore we reject the formulation implicit in equation 3.37.

Equation 3.36 has coefficient values very similar to those of equation 3.37. The estimate of MC which is the inverse of the coefficient of the constant term is \$ 1.2966. This estimate is very close to that obtained from equation 4.35. The estimate of elasticity of demand is 3.6267. The coefficients are all greater than twice the value of their standard errors and therefore highly significant. The DW statistic of 1.41 does not enable us to reject conclusively the hypothesis of no autocorrelation at the 5 % level since the DW falls in the inconclusive range. However, at the 1 % level of significance, the hypothesis can be rejected. The turning points are modelled well by this equation. The only turning point not forecasted is the one in 1974. This turning point is picked up after a lag of two years in 1976. The fitted values also over predict the turning points of 1954 and 1955 (see graph 3).

Graph 3

Actual Price Versus Predicted (Fitted) Price for
Equation (3.36), 1953 - 1978 (Dollars per Pound)



The root mean squared percent error of the predicted values is 5.38 %. This is marginally higher than the RMSE % of equation 3.35 of 5.15 %.

On grounds of RMSE, DW statistic, plots of the actual and fitted values, and significance of coefficients it seems that equation 3.35 is the best equation estimated.

In the next chapter the demand functions for five major cobalt consuming countries and the noncommunist world as a whole are discussed.

IV DEMAND FUNCTIONS FOR THE REST OF THE WORLD

In this chapter we present estimates of demand functions for five of the major industrialised countries, namely, United Kingdom, Japan, France, Germany and Italy. These countries were chosen because in the period 1966 - 1976 for which data on cobalt consumption are available, the consumption in these five nations exceeded 500 metric tons⁽¹⁾. An aggregated demand function for the noncommunist world excluding USA is also estimated. We first discuss the individual country demand functions and then the aggregated non-communist demand function for cobalt⁽²⁾.

4.1 Country Demand Functions

The econometric estimation of the country demand functions was carried out using the deflated price of cobalt and the index of industrial production as independent variables. The price of cobalt in each country was calculated by first multiplying the cobalt price quoted in dollars with the exchange rate prevailing between the country and USA. The exchange rate quotations used were dollars per unit of the country's currency. This cobalt price was then deflated by the country's wholesale price index. An "inverted-V" and geometric lag structures were tried on all the demand equations

(1) People's Republic of China, USSR and USA are the only three other countries for which cobalt consumption exceeded 500 tons. Data on price and activity variables are not available for the USSR and People's Republic of China so demand functions for these countries could not be estimated. The econometric estimation of cobalt consumption in different end use categories for the United States has already been discussed in the previous chapter.

(2) The appendix lists the various data sources.

estimated⁽¹⁾. Both linear and loglinear forms were tried. Where both these forms performed equally well the logarithmic form was chosen.

4.1.1 Demand Function for Japan

A demand function for Japan was estimated using the price of cobalt (PC), and the price of nickel (PN) in terms of yens per pound, and the index of industrial production (YJ). The results are reported in table 4.1. The geometric lag version was unsuccessful. The lagged cobalt consumption in Japan had a coefficient value considerably smaller than twice the asymptotic standard error. This version has therefore not been reported here. A two, three and six year "inverted-V" distribution was tried for the price of cobalt both in the logarithmic and the untransformed regressions. Price of nickel was introduced both as a current variable and with an "inverted-V" distribution. From the table it is evident that nickel was insignificant in all the regressions estimated. The best equations estimated were 4.14 and 4.15. 4.15 is slightly superior to 4.14 both in terms of significance of coefficients and the t-statistic. This equation was therefore chosen to calculate the elasticities. The elasticity with respect to price of cobalt in the short run is 0.06534 and elasticity in the long run is 1.013. The elasticity with respect to the activity variable, YJ, is 1.3516⁽²⁾.

(1) A geometric lag structure having the current price of cobalt as an explanatory variable was not tried. This was because to estimate such an equation Fair's estimation technique is required. This technique uses lagged dependent variable, price of cobalt lagged, and index of industrial production lagged as instrumental variables in addition to others such as government stocks lagged, and net purchases by the government. Since the number of observations available to us was only eleven this would have meant a loss of too many degrees of freedom.

(2) The mean deflated cobalt price is 0.00699225 and the mean of YJ is 98.3434.

Table 4.1

Dependent Variable is the Transformed/Untransformed : Cobalt Consumption in Japan, lnCCJ, Period of Estimation 1966 - 1976

Equation	C	$\sum_{i=0}^6 w6_i \ln PC_{-i}$	$\sum_{i=0}^2 w2_i \ln PN_{-i}$	$\sum_{i=0}^6 w6_i \ln PC_{-i}$	lnPN	$\sum_{i=0}^3 w3_i \ln PN_{-i}$	lnYJ	DW
4.11	-10.98 (- 1.5)	-0.7654 (-1.304)			-0.4666 (-0.5969)		1.3986* (2.06)	2.356
4.12 using $\sum_{i=0}^2 w2_i \ln PN_{-i}$ in 4.11	-10.823 (- 0.860)	-0.5545 (-0.4353)	-0.611425 (-0.2874)				1.411 (1.1)	2.3219
4.13 using $\sum_{i=0}^3 w3_i \ln PN_{-i}$ in 4.11	- 7.626 (- 0.666)	-0.8307 (-0.301)				-0.0814 (-0.0206)	1.0827 (0.828)	2.318
4.14 dropped nickel from 4.11, 4.12, 4.13	- 7.3707 (- 1.815)	-0.881377 (-1.6597)					1.0543* (3.0016)	2.3127
4.15 equation 4.11 in untransformed variables	4.4798* (2.174)			-1003.66 (- 1.83566)			0.0829969* (3.17365)	2.208

Notes:

An asterisk denotes coefficients atleast twice the value of their asymptotic standard errors.

The instrumental variables that have been used are DQS and QSI.

4.1.2 Demand Function for West Germany

Linear, loglinear, "inverted-V" and geometric lag versions were estimated using the price of cobalt, the price of nickel and index of industrial production (YG) as activity variables. The loglinear equations were more significant than the linear equations. Also a two year "inverted-V" lag structure for price of cobalt performed better than the other lag structures so table 4.2 reports results of loglinear equations having only a two year lag structure, with and without price of nickel⁽¹⁾.

The equations, 4.21, 4.22, 4.23, in which both the price of nickel and cobalt were introduced gave wrong signs for the price of cobalt variable. In all equations estimated the sign was positive whereas economic theory requires the sign to be negative. Since in West Germany the maximum use of cobalt is probably in the production of radios, televisions and other stereophonic equipment in which nickel is a substitute for cobalt the sign of nickel was expected to be negative. This expectation was confirmed in the regression equations estimated with nickel also included as an independent variable. Estimation of the correlation coefficient between nickel and cobalt revealed a correlation of nearly 0.9. The wrong sign of cobalt could therefore be due to strong multicollinearity between the two price variables. Therefore in equation 4.24 the logarithm of the ratio of prices of cobalt and nickel ($\ln DP$) was introduced. This has the right sign because when price of cobalt goes up relatively to price of nickel, the cobalt consumption would be expected to fall. The coefficient of $\ln DP$ is, however, not

(1) The other results can be obtained from the author.

Table 4.2

Dependent Variable is the Logarithm of Cobalt Consumption in Germany, $\ln COG$, Period of Estimation 1966 - 1976

Equation	C	$\sum_{i=0}^2 w_{2i} \ln PC_{-i}$	$\ln DP$	$\ln PN$	$\sum_{i=0}^2 w_{2i} \ln PN_{-i}$	$\sum_{i=0}^3 w_{3i} \ln PN_{-i}$	$\ln YG$	DW
4.21	-13.318* (- 2.007)	1.3547 (1.500)		-2.038 (-1.783)			2.937* (2.26)	1.7586
4.22 using $\sum_{i=0}^2 w_{2i} \ln PN_{-i}$ in 4.21	-13.3184* (- 2.007)	1.35468 (1.500)			-2.03827 (-1.783)		2.937* (2.26)	1.7586
4.23 using $\sum_{i=0}^3 w_{3i} \ln PN_{-i}$ in 4.21	12.609 (0.32)	1.238 (0.3469)				-1.7699 (-0.40328)	-2.5947 (-0.2899)	1.5826
4.24 using $\ln DP$ instead of $\ln PN$ and $\sum_{i=0}^2 w_{2i} \ln PC_{-i}$ in 4.21	- 1.0028 (- 0.399)		-0.160447 (-0.16717)				0.57435 (1.2189)	1.5657
4.25 dropped $\ln PN$ from equation 4.21	- 2.898 (- 0.9356)	-0.1729 (-0.6421)					0.94935 (1.447)	1.4854

Notes:

The instrumental variables used have been DGS and GSI.

statistically significant. In equation 4.25 price of nickel is dropped. This equation does not really perform better than any of the other four equations.

Equation 4.21 was the best equation estimated. The DW of 1.7586 permits the rejection of the hypothesis of positive autocorrelation. The coefficient of C and $\ln YG$ are significant and the coefficient of $\ln PN$ is also quite close to twice the value of its standard error. The substitution elasticity is -2.038. The price elasticity in the long run is 1.3547 and in the short run is 0.3387⁽¹⁾. The elasticity with respect to YG is 2.937.

4.1.3 Demand Function for France

A demand function for France was estimated with price of cobalt, price of nickel, and an index of industrial production for France (YF) as independent variables. In this demand function the same problem of collinearity between the two price variables was observed. Hence in equation 4.34, the logarithm of the ratio of price of cobalt to the price of nickel was introduced. It is interesting to note that in 4.34 the index of industrial production is statistically significant whereas in 4.31 to 4.33 it is insignificant. The ratio variable, $\ln DP$ however, has the wrong sign and the coefficient is also insignificant. Equation 4.35, with only the price of cobalt and YF is quite similar to equation 4.34. The coefficients of the price and the activity variables are fairly close to each other and so is the DW statistic of both equations. Since, in equation 4.35 the coefficient of PC is readily interpretable as the long run elasticity of price of cobalt, equation 4.35 was chosen over 4.34. The long run price elasticity is very small, only 0.13356. The elasticity in the

(1) One must note that since the sign of price of cobalt is wrong and the coefficient insignificant, the elasticity measure is very approximate.

Table 4.3

Dependent Variable is the Logarithm of Cobalt Consumption in France, $\ln CCF$, Period of Estimation 1966 - 1976

Equation	C	$\sum_{i=0}^2 w_{2i} \ln PC_{-i}$	$\ln DP$	$\sum_{i=0}^2 w_{2i} \ln PN_{-i}$	$\ln PN$	$\ln YF$	$\sum_{i=0}^3 w_{3i} \ln PN_{-i}$	DW
4.31	-4.071 (-1.284)	0.350387 (0.50976)			-0.37466 (-0.62209)	1.03637 (1.9093)		1.7524
4.32 using $\sum_{i=0}^2 w_{2i} \ln PN_{-i}$ in 4.31	-7.8324 (-0.3858)	0.664166 (0.31933)		-1.3136 (-0.248)		1.60566 (0.5225)		1.6047
4.33 using $\sum_{i=0}^3 w_{3i} \ln PN_{-i}$ in 4.32	5.984 (0.387)	-0.7235 (-0.43153)				-0.44566 (-0.1942)	2.9244 (0.5802)	1.4956
4.34 using $\ln DP$ in 4.31	-3.5288 (-1.825)		0.124189 (0.13109)			0.954935* (2.74047)		1.603
4.35 without nickel in 4.31	-2.9456 (-1.247)	0.13356 (0.22648)				0.869566* (2.005)		1.6235

Notes:

Instrumental variables used have been DGS and GS1.

short run is 0.0339. The elasticity with respect to index of industrial production is 0.8695⁽¹⁾.

4.1.4 Demand Function for Cobalt Consumption in Britain

Various forms of demand functions were estimated using different lag structures for cobalt and nickel as well as the ratio of the two in linear and loglinear regressions. In all the regressions estimated including the geometric lag regressions, the coefficients of all the price and activity variables, PC, PN and the index of industrial production in Britain (YU) were insignificant, and in most cases the variables had wrong signs. The insignificance of YU was not surprising considering the fact that most cobalt consumption in Britain is probably concentrated in the production of jet aircrafts so that YU is a poor proxy for the activity variable reflecting cobalt consumption. However, data on jet engine production for Britain was not available. Since the results for Britain were insignificant they have not been reported here.

4.1.5 Demand Function for Italy

Demand functions for Italy were estimated using the deflated price of cobalt and nickel in Italy and the index of industrial production (YI). The regressions results were very poor. The variables had wrong signs and/or low significance values, so the regression estimates could not be used to calculate elasticities.

(1) Price of cobalt in 3.35 is insignificant.

The generally poor performance of the country demand functions can be attributed to the poor quality of the data and to the smallness of the time series available for regression estimation. The demand functions estimated for the non-communist world as a whole presented in the next section gave better results.

4.2 Demand Function for the Noncommunist World

The demand function for the noncommunist world was estimated using consumption of cobalt in noncommunist countries (CBWX and TNCC) as the dependent variable. Deflated price of cobalt (WC) and weighted average of index of industrial production in major noncommunist countries (WIIP) were used as the independent variables. The construction of the dependent and independent variables is discussed in the next section (4.2.1) and the empirical results are presented in section 4.2.2.

4.2.1 Construction of WC and WIIP⁽¹⁾

The deflated price of cobalt in the noncommunist world (WC) was calculated by dividing the price of cobalt in current US dollars by the weighted wholesale price index of major cobalt consuming countries (WPMCCC)⁽²⁾. The weighted index of industrial production was estimated as follows:

$$WIIP = \frac{[(7.81) YB + (4.63) YC + (10.71) YE + (9.68) YF + (18.29) YG + (7.51) YI + (39.24) YJ + (2.13) YN_7]}{100}.$$

The weights are the percentage shares of each country in the crude steel production of the entire group for the period 1969 - 1973⁽³⁾.

(1) The construction of CBWX and TNCC has already been discussed in chapter 3.

(2) The calculation of WPMCCC has also been explained in chapter 3.

(3) For a similar approach, see Charles River Associates (1976).

4.3 Results

Demand functions were estimated in linear and loglinear forms. Both geometric and "inverted-V" lag structures were tried. The geometric lag versions did not give satisfactory results. The lagged cobalt consumption in noncommunist countries was insignificant. The proxy CBWX for cobalt consumption gave superior results as compared to TNCC. All the regressions estimated using TNCC had insignificant coefficients. This result was expected given the poor performance of the country demand functions. Deflated price of nickel (WN) calculated in a way similar to deflated price of cobalt was introduced as a substitute variable. WN had the expected sign but a coefficient value smaller than twice the value of its asymptotic standard error. WN was introduced both as a current and with lagged values. A two and three year lag structures for the price of cobalt gave a better value for the DW statistic and higher significance values as compared to a six year lag structure. The results of two and three year lag structures for WC and WN are reported in table 4.4.

The performance of different lag structures for price of cobalt is very similar in all the equations estimated. Nickel is insignificant both in its current and lagged forms. When nickel is dropped altogether the DW statistic and significance values improve considerably. For example, see equations 4.44 and 4.48. The DW statistic of both equations show the absence of autocorrelation. The activity variable is significant in both equations, though slightly more so in the case of 4.44. The price variable is insignificant in both equations but in equation 4.48 the coefficient of WC is closer to twice the value of its standard error. It is worth noting that the coefficient of WC is quite sensitive to the length of the lag structure postulated. A three year lag structure gives a higher

Table 4.4

Dependent Variable is the Logarithm of the Noncommunist Cobalt Consumption, $\ln C_{NW}$, Period of Estimation 1953 - 1978

Equation	C	$\sum_{i=0}^2 w_{2i} \ln WC_{-i}$	$\sum_{i=0}^3 w_{3i} \ln WC_{-i}$	$\sum_{i=0}^2 w_{2i} \ln WN_{-i}$	$\sum_{i=0}^3 w_{3i} \ln WN_{-i}$	$\ln WN$	$\ln WIIP$	DW
4.41 $\sum_{i=0}^2 w_{2i} \ln WC_{-i}$ and $\ln WN$	-1.67* (-3.829)	-0.31294 (-1.7453)				-0.25313 (-0.92217)	1.1955* (13.292)	1.8337
4.42 $\sum_{i=0}^2 w_{2i} \ln WN_{-i}$ in 4.41 instead of $\ln WN$	-2.03* (-2.42)	-0.29996 (-1.6349)		-0.45906 (-0.79)			1.275* (6.812)	1.7732
4.43 $\sum_{i=0}^3 w_{3i} \ln WN_{-i}$ in 4.41 instead of $\ln WN$	-2.3745 (-1.477)	-0.3067 (-1.552)			-0.8263 (-0.6017)		1.353* (3.693)	1.6564
4.44 dropped $\ln WN$ from 4.41	-1.4356* (-4.074)	-0.27726 (-1.5924)					1.1364* (18.125)	1.91
4.45 $\sum_{i=0}^3 w_{3i} \ln WC_{-i}$ in 4.41	-1.4864* (-2.914)		-0.43375 (-1.6907)			-0.1986 (-0.7158)	1.1603* (11.761)	1.7376
4.46 $\sum_{i=0}^2 w_{2i} \ln WN_{-i}$ instead of $\ln WN$ in 4.45	-1.7537 (-1.943)		-0.4207 (-1.6066)	-0.34725 (-0.5925)			1.2191* (6.254)	1.6984
4.47 $\sum_{i=0}^3 w_{3i} \ln WN_{-i}$ in 4.45	-1.9702 (-1.217)		-0.4315 (-1.571)		-0.5942 (-0.4406)		1.2688* (3.491)	1.6212
4.48 dropped $\ln WN$ from 4.45	-1.286* (-3.055)		-0.41462 (-1.6463)				1.1123* (15.58)	1.8121

Notes:

The instrumental variables used are DGS, PN, WN (weighted nickel price).

estimate of long run elasticity than a two year lag structure. The estimate of 0.41462 in equation 4.48 seems to be a more realistic measure of long run price elasticity than the estimate of 0.27776 in equation 4.44⁽¹⁾. Hence equation 4.48 was chosen to be the best equation estimated. The long run price elasticity of demand is 0.41462, short run elasticity is 0.07048, and elasticity with respect to the activity variable, WIIP, is 1.1123.

In the next chapter the simulation results are presented.

(1) A six year lag structure not reported here also gave an estimate of cobalt 0.42.

V SIMULATION

The end use demand equations estimated for the US in chapter II, the producer price behaviour equation estimated in chapter III and the total cobalt consumption in the noncommunist world estimated in chapter IV were used to simulate the effects of the disposal of US government stocks of cobalt and a change in the producer price behaviour of major cobalt producers. The supply shock to the model in the form of GSA sales or the start of seabed mining can be simulated by altering the variable DGS, the net government additions to strategic stockpile⁽¹⁾.

The complete simulation model can be specified^(2,3) as:

$$\begin{aligned} \ln \text{CCSA} = & -3.06515 + 0.492534 \ln \text{YJET} - 0.36196 \sum_{i=0}^6 \ln \text{PC}_{-i} \\ & + 0.2825 \ln \text{TURB} - 0.39838 \text{DGS} \end{aligned} \quad (5.1)$$

-
- (1) Because the start of seabed mining is not directly involved in the operation of the model, the effect of increased supply of cobalt from seabed mining would also have to be implemented by changing DGS. Infact, two separate experiments would not be required.
 - (2) The period of estimation of demand equations for cobalt consumption in superalloys, CCSA, and hardfacing rods and materials, CHM, was 1953 - 1975 in chapter II. This was because data on YJET, the activity variable common to both demand functions was not available for 1975 - 1978. Since, a 1979 simulation requires that all end use demand equations be estimated upto 1978 these demand equations were re-estimated using forecasted data on jet engines for 1975 to 1978 presented by the Charles River Associates report 1976. This data is given in appendix C.
 - (3) For simulation purposes cobalt consumption in other nonmetallic uses, CONM, and catalysts, CCA, was combined to form one category, cobalt consumption in all nonmetallic uses, CON. The demand function for CON was estimated for the period 1953-1978. This was because the data for CONM and CCA was available only for twelve years, 1967- 1978. For good simulation it is desirable to have equations in the simulation model estimated over a reasonably long time period. The best equation estimated for CON had a DW of 1.65 and coefficients greater than twice the value of their standard errors.

$$\text{CCM} = -1.94 - 0.024\text{PC} + 2.72\text{PN} + 0.0312\text{YTV} + 0.381\text{CCM1} - 0.27\text{DMA2} \quad (5.2)$$

$$\ln\text{CWR} = -3.596 - 0.6154 \sum_{i=0}^6 w6_i \ln\text{PC}_{-i} + 0.9667 \ln\text{NELM} \quad (5.3)$$

$$\ln\text{CSD} = -11.028 + 1.4367 \ln\text{YPET} - 0.346 \text{DLEAD} - 0.1895 \sum_{i=0}^6 w6_i \ln\text{PC}_{-i} - 0.1013 \ln\text{PL} \quad (5.4)$$

$$\text{CHM} = -0.2064 - 0.654408\text{DHF} + 0.0000116437\text{YJET} + 0.0012939\text{YW} - 0.0302006 \sum_{i=0}^6 w3_i \text{PC}_{-i} \quad (5.5)$$

$$\text{CON} = 0.5787 - 0.4658 \text{PC} + 0.00043 \text{YPET} \quad (5.6)$$

$$\ln\text{COM} = -4.47787 - 1.07271 \sum_{i=0}^2 w3_i \ln\text{PC}_{-i} + 1.19764 \ln\text{YIP} - 1.25948 \sum_{i=0}^2 w2_i \ln\text{PN}_{-i} \quad (5.7)$$

$$\ln\text{CBWX} = -1.286 - 0.41462 \sum_{i=0}^3 w3_i \ln\text{WC}_{-i} + 1.1123 \ln\text{WIIP} \quad (5.8)$$

$$\text{PBDW} = 1.26276 + 1.06275\text{D6} + 0.36063\text{D7} + 2.1892\text{D8} + 0.057934\text{DGS} + 0.016575\text{D} \quad (5.9)$$

Closing the Model⁽¹⁾

$$\text{D} = \text{CCSA} + \text{CCM} + \text{CWR} + \text{CSD} + \text{CCA} + \text{CHM} + \text{CON} + \text{COM} + \text{CBWX} \quad (5.10)$$

$$\text{PC (deflated)} = \frac{\text{PC}}{\text{PMM}} \quad (\text{current dollars}) \quad (5.11)$$

$$\text{WC} = \frac{\text{PC}}{\text{WPMCCC}} \quad (\text{current dollars}) \quad (5.12)$$

$$\text{PBDW} = \text{PC} / [0.2901681 (\text{PMM}/1.167) + 0.7098319 (\text{WPMCCC})] \quad (5.13)$$

(1) The price of cobalt, PC, used in the demand equations above is deflated by the price index of metal and metal products. The price is not in terms of current dollars.

The thirteen endogenous variables in the above simulation model are (1) cobalt consumption in all of the seven end use categories in the US, (2) cobalt consumption in the noncommunist world (3), total demand, D, (4) PC in current dollars, (5) deflated price of cobalt, (6) WC, and (7) PBDW. For all the exogenous variables in the system of equations, estimates are required to simulate over a forecast period but not over the historical period for which the model was estimated. Since, the effects of a change in the producer price behaviour were simulated for 1979 the values of all the exogenous variables had to be obtained for 1979. In most cases data for 1979 was available from the sources listed in appendix A. Additional notes on exogenous variables not readily available are given in appendix C.

5.1 Simulation Results of a Change in Producer Price Behaviour

Here, the price of cobalt was set equal to the MC of producing cobalt. Given the price the end use demand in the US and in the rest of the noncommunist world was estimated. Since, the price of cobalt is now assumed to be exogenously determined, the producer price behaviour equation 5.9, and equations 5.11 to 5.13 were eliminated from the model. Only the equations 5.1 to 5.8 and 5.10 were retained. The simulated values for 1979 are given in table 5.1.

Table 5.1

Demand Simulations when MC Pricing Followed by the Cartel

Consumption Category	Cobalt Consumption (Millions of Pounds)
CCSA	3.4982
CCM	4.41811
CWR	2.26234
CSD	3.80129
CHM	0.64829
CON	2.66263
COM	1.77244
CBWX	45.36723
D	64.4305

In Table 5.1 above the total consumption, D, is 64.4305 million pounds. In 1978 D was 63.896. Hence a MC pricing policy by decreasing the price of cobalt has raised the overall consumption of cobalt. The increase, however, does not seem very significant. This is because CCSA, CSD, CHM and CBWX fell. This was on account of the relatively low elasticities with respect to price and the lag structures appearing in each of the demand equations in some cases as much as six years in length. In a long lag structure only a very small weight (0.063 in case of a six year lag) is placed on the current price of cobalt. Therefore, even though current deflated price fell, cobalt consumption did not rise. Of the four demand variables which registered a fall, CCSA, CSD had a six year and CHM, CBWX had a three year "inverted-V" lag structure. The implication of this result is that a MC pricing policy followed consistently for a span of at least six years could (though not necessarily) raise cobalt consumption levels substantially but not in the short run (1 year in length). The other factor influencing cobalt consumption is the income or the activity variable. Cobalt consumption in CCSA and CHM declined also because YJET in 1979 was only 3364.144 whereas in 1978 it was 3836. Similarly YPET which enters as the activity variable in CSD declined from 5500.8 in 1978 to 5456.7 in 1979.

5.2 Simulation Results of Disposal of Government Stocks

It was assumed that the US government disposed two million pounds of cobalt from its strategic stockpile in 1979. Then given that DGS is -2 for 1979 the values of all the endogenous variables were estimated using the simulation model.

The results are presented in table 5.2.

Table 5.2

Simulated Values from Disposal of US Stocks of Cobalt, 1979

Endogeneous Variable	Value
CCSA	3.4446
CCM	4.3680
CWR	2.204
CSD	3.7707
CHM	0.6509
CON	1.6907
COM	1.5665
CBWX	42.9501
D	60.646
PBDW	2.5127
PC (current)	6.45
PC (deflated)	2.5945
WC	2.3493

When the government stocks were disposed, the price of cobalt in current dollars fell to 6.45004. US deflated price of cobalt, noncommunist deflated price of cobalt, WC, and world deflated price of cobalt, PBDW, all fell. However, consumption in some end use categories did not rise if a comparison is made between their 1978 actual and 1979 simulated values. The possible reasons for a fall in consumption in 1979 even though price fell have been discussed in the previous section. Some additional points are, however, worth noting. First, the value of the price variable $\sum_{i=0}^6 w_6 \ln PC_{-i}$ in 1979 is composed of the weighted average of the deflated price of cobalt from 1973 to 1979, and this figure is higher than the 1978 value of $\sum_{i=0}^6 w_6 \ln PC_{-i}$ computed for the period 1972 to 1978. For example, in 1978 $\sum_{i=0}^6 w_6 \ln PC_{-i}$ was 0.85105 but in 1979 it was 0.94029. Hence despite the decline in current and deflated price of cobalt in 1979 to \$ 6.45/pound and \$ 2.595/pound respectively the weighted price variable entering the demand equation did not fall.

This brings us back to the same point discussed in section 5.1 i.e. the lag structure is constructed so as to assign a small weight on the most recent price figure so that the effect of a decline in price in one period does not really show up in the consumption figures. Second, the appropriate comparison is between disposal of 2 million stocks and zero stocks and not between 1978 and 1979 values of the endogenous variables.

VI CONCLUDING COMMENTS

This report analysed the structure of the cobalt industry and presented an econometric model of the world cobalt market. At the outset, the production and consumption structures were discussed. The potential and existing sources of supply in the short and the long run were examined. Production of cobalt was found to be concentrated in few hands. The picture with regard to consumption was different. Though, the US was the major consumer of cobalt, consumption was widely dispersed over Asian, European and the Communist bloc countries. The discussion on production and consumption was followed by a discussion on future trends in demand and supply and price of cobalt. Demand and supply were expected to balance in the long run with the advent of seabed mining but, there were likely to be imbalances in the short run with demand exceeding supply. The price of cobalt in constant 1978 dollars increased relatively slowly though steadily between 1957 and 1977. In 1978 there was a sudden jump from \$ 5.99 per pound to \$ 11.53 per pound.

In chapter II end use demand functions were calculated for the US. The aggregate end use elasticity of demand was estimated to be 0.073 in the short run and 0.95 in the long run. These estimates obtained were, however, the 'minimum' estimates because they were not adjusted for the technological change. If the technological factor is accounted for which Burrows estimates to be atleast 0.5, then these estimates would have to be revised upwards to 0.573 and 1.45 respectively.

Chapter III formulated the producer price behaviour of Zaire. Econometric estimation supported a cartellized behaviour where Zaire cooperates with other producers in setting the price.

In chapter IV an attempt was made to estimate the demand functions for other major cobalt consuming countries, Britain, Japan, Italy, W. Germany and France. The country demand functions did not in general give very satisfactory econometric results. This was probably due to inadequacies in the data base and the very short time period for which the data was available. In view of the unsatisfactory nature of the results of the country demand function, an aggregate noncommunist demand function was estimated. The short and long run aggregate noncommunist demand elasticities were found to be 0.0704 and 0.414 respectively.

In chapter V the simulation model was developed from the end use demand equations for the US, the producer price behaviour equation and the aggregate demand function for the noncommunist world. The effects of a supply shift from the disposal of US government stocks of strategic cobalt or from the advent of seabed mining were simulated. Another set of simulation results were obtained by postulating a producer price behaviour where the price of cobalt was set to equal MC.

The major contribution of this study lies in

- a) updating the cobalt study by Burrows and by other authors,
- b) in estimating demand equations using both the geometric and "inverted-V" distributions for price of cobalt,
- c) in estimating a demand function for consumption of catalysts,
- d) in making use of better estimation techniques (like Fair's estimation) to estimate demand equations in which both the simultaneity bias and first order autocorrelation were present,
- e) in using better proxies for activity variables,

- f) in reformulating the producer price behaviour in view of the recent decline in production share accounted for by Zaire,
- g) in estimating country demand functions for cobalt consumption in the noncommunist world,
and lastly,
- h) in simulating the effects of a change in producer price behaviour and exogenous supply shifts.

Appendix A

Variables Used in the Analysis

<u>Symbol</u>	<u>Years</u>	<u>Units</u>	<u>Title</u>	<u>Source</u>
CEWX	1947 - 1978	Million Pounds	Non-communist World Consumption of Cobalt, excluding US (CEWX = QEW - CUST - DGS)	Construct
CCA	1967 - 1978	Million Pounds	US Consumption of Cobalt in Catalytic Applications	1,19
CCM	1947 - 1978	Million Pounds	US Consumption of Cobalt in Magnets	1,19
CCSA	1947 - 1978	Million Pounds	US Consumption of Cobalt in Superalloys	1,19
CF	1966 - 1976	Million Pounds	Consumption of Cobalt in France	20
CG	1966 - 1976	Million Pounds	Consumption of Cobalt in Germany	20
CHF	1947 - 1978	Million Pounds	US Consumption of Cobalt in Welding and Hardfacing Rods and Materials	1,19
CJ	1966 - 1976	Million Pounds	Consumption of Cobalt in Japan	20
CI	1966 - 1976	Million Pounds	Consumption of Cobalt in Italy	20
COM	1960 - 1978	Million Pounds	US Consumption of Cobalt in Other Metallic Applications	1,19
CONM	1967 - 1978	Million Pounds	US Consumption of Cobalt in Other Nonmetallic Applications	1,19
CSD	1947 - 1978	Million Pounds	US Consumption of Cobalt in Salts and Driers, for Lacquers, Paints etc.	1,19
CU	1966 - 1976	Million Pounds	Consumption of Cobalt in the UK	20
CUST	1947 - 1978	Million Pounds	Total US Industrial Consumption of Cobalt	1,19
CWR	1947 - 1978	Million Pounds	US Consumption of Cobalt in Tool Steel and Cutting and Wear Resistant Alloys	1,19
D4	1947 - 1978	1947 - 1950 = 1 ^a	Korean War Dummy	-
D41	1947 - 1978	1958 - 1978 = 1 ^a	Civilian Jet Dummy	-
D54S	1947 - 1978	1954, 1968 = 1 ^a	YJET War Dummy	-
D6	1947 - 1978	1947 - 1956 = 1 ^a	Dummy Variable For Magnet Demand	-
D7	1947 - 1978	1967 - 1978 = 1 ^a	Dummy for Congo Takeover	-
D8	1947 - 1978	1978 = 1 ^a	Dummy for Exceptional Events of 1978	-
DCERT	1947 - 1978		US Personal Consumption Expenditure on Radios, TVs etc.	D.O.C. National Inc. and Prod., Table 2.6
DGS	1947 - 1978	Million Pounds	Net US Government Purchases of Cobalt GS - GS (-1) ₇	Construct
DHF	1947 - 1978	1968 - 1978 = 1 ^a	Dummy for Hardfacing Structural Change	-
DLead	1947 - 1978	1947 - 1968 = 1 ^a	Dummy for Change in Regulations Concerning Lead Content of Paints	-
DMA	1947 - 1978	see text	Dummy No. 2 for Magnet Demand Shift	-
DTURB	1947 - 1978	see text	Turbine Demand Dummy	-
EUB	1947 - 1979	US Dollars/Franc	US - Belgium Exchange Rate	2, 3
EUC	1949 - 1979	US Dollars/Can. Doll.	US - Canadian Exchange Rate	2, 3
EUF	1947 - 1979	US Dollars/1963 Franc	US - France Exchange Rate	2, 3
EUG	1949 - 1979	US Dollars/DM	US - Germany Exchange Rate	2, 3

<u>Symbol</u>	<u>Years</u>	<u>Units</u>	<u>Title</u>	<u>Source</u>
EUI	1949 - 1979	US Dollars/Lire	US - Italy Exchange Rate	2, 3
EUJ	1949 - 1979	US Dollars/Yen	US - Japan Exchange Rate	2, 3
EUN	1949 - 1979	US Dollars/Guilder	US - Netherlands Exchange Rate	2, 3
EUU	1949 - 1979	US Dollars UK/Pound	US - UK Exchange Rate	2, 3
GS	1946 - 1978	Million Pounds	US Government Stocks of Cobalt	1, 2, 4
NELM	1947 - 1978	1967 = 100	Index of Production of Nonelectrical Machinery	11
PC	1947 - 1978	Dollars/Pound	Price of Cobalt ^b	2, 6
PL	1947 - 1979	Dollars/Pound	Price of Lead	5
PT	1956 - 1977	Dollars/Pound	Price of Tungsten ^b	7
PM	1954 - 1978	Dollars/Pound	Price of Manganese ^b	8
PMO	1947 - 1978	Dollars/Pound	Price of Molybdenum ^b	9
PMM	1947 - 1979	1967 = 100	US Bureau of Labor Statistics Wholesale Price Index of Metal and Metal Products	10
PN	1947 - 1979	Dollars/Pound	Price of Nickel	6
PBDW	1947 - 1978	Dollars/Pound	World Deflated Price of Cobalt	Construct
QEW	1947 - 1978	Million Pounds	World Production of Cobalt	Construct
QEWCEG	1947 - 1978	Million Pounds	World Consumption of Cobalt (CUST + CBWX)	Construct
QBZAI	1947 - 1978	Million Pounds	World Production of Cobalt excluding Zaire	Construct
QBX	1947 - 1978	Million Pounds	Exogeneous World Supply of Cobalt (QBZAI - DGS)	Construct
WIIP	1947 - 1979	1970 = 100	Weighted Index of Industrial Production in Europe and Japan	Construct
WFB	1947 - 1979	1970 = 100	Wholesale Price Index of Belgium	2,12
WPC	1947 - 1979	1970 = 100	Wholesale price Index of Canada	2,13
WPF	1947 - 1979	1970 = 100	Wholesale Price Index of France	2,12
WPG	1947 - 1979	1970 = 100	Wholesale Price Index of Germany	2,13
WPI	1947 - 1979	1970 = 100	Wholesale Price Index of Italy	2,12
WPJ	1947 - 1979	1970 = 100	Wholesale Price Index of Japan	2,12
WPMCCC	1947 - 1979	1970 = 100	Index of Wholesale Prices in Major Cobalt Consuming Countries Excluding US	Construct
WPN	1947 - 1979	1970 = 100	Wholesale Price Index of Netherlands	2,12
WPU	1947 - 1979	1970 = 100	Wholesale Price Index of UK	2,12
YB	1947 - 1979	1970 = 100	Industrial Production Index of Belgium	2,12
YC	1947 - 1979	1970 = 100	Industrial Production Index of Canada	2,12
YCT	1947 - 1978	Million Dollars	US Value of Shipments of Small Cutting Tools ^b	14
YDSE	1947 - 1978	1967 = 100	US Index of Production of Defence and Space Equipment	15, 16
YDUR	1947 - 1978	1967 = 100	US Index of Production of Durable Goods	11
YELM	1947 - 1978	1967 = 100	US Index of Production of Electrical Machinery	11

<u>Symbol</u>	<u>Years</u>	<u>Units</u>	<u>Title</u>	<u>Source</u>
YF	1947 - 1979	1970 = 100	Industrial Production Index of France	2,12
YG	1947 - 1979	1970 = 100	Industrial Production Index of Germany	2,12
YI	1947 - 1979	1970 = 100	Industrial Production Index of Italy	2,12
YIP	1947 - 1979	1970 = 100	US Index of Industrial Production	11
YJ	1947 - 1979	1970 = 100	Industrial Production Index of Japan	2,12
YJD	1958 - 1978	Number	US Commercial Jet Airplane Deliveries ^d	
YJET	1947 - 1975	Number	US Production of Jet Engines	2,17
YN	1947 - 1979	1970 = 100	Industrial Production Index of Netherlands	2,12
YPET	1947 - 1979	Millions of Barrels	Crude Oil Runs to Distillation Units	15
YSP	1951 - 1978	Billions of Dollars	US Value of Shipments of Paints, Lacquers and Varnishes	15
YTV	1947 - 1972 and 1976 - 1978	1967 = 100	Index of Production of Radios and TVs	16
YU	1947 - 1979	1970 = 100	Index of Industrial Production in UK	2,12
YW	1947 - 1978	Millions of Pounds	Index of Production of Arc Welding Electrodes in the US	18

Notes:

- a All other years equal 0.
- b Deflating by US wholesale price index of metal and metal products (PMM).
- d Personal communication with Boeing office in Hamburg, W. Germany.

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Appendix B

Additional Notes to some Variables

- I Consumption of Cobalt in End Use Categories:
Data for the period 1947 - 1976 was collected from the various issues of the Mineral Yearbook and data for 1977 and 1978 was obtained from the Metal Statistics of 1979.
- II Consumption of Cobalt in Countries:
The data are reported in metric tons. The figures were converted to pounds.
1 ton = 2204.6 pounds
- III Government Stocks of Cobalt:
For the period 1947 - 1974 the data was collected from the CRA report (see source 2). Data for 1975 - 1978 was obtained from the Mineral Commodity Summaries.
- IV Exchange Rate for Major European Countries and Japan:
Data for 1949 - 1974 was collected from the CRA report, and data for 1975 - 1978 from the Federal Reserve Bulletin.
- V Wholesale Price Indices for Major European Countries and Japan:
The wholesale price index for UK is the index for "Finished Goods".

The wholesale price index for France is the index for "Industrial Products". Prices include tax.

The wholesale price index of Germany is described by IFS to be the index for "Industrial Products".

The wholesale price index of Italy is a "general" index.

The wholesale price index of Japan is also a "general" index.

The wholesale price index of Netherlands is the index for "Final Products".

The wholesale price index of Belgium is a "general" index.

The wholesale price index of Canada represents "Industrial Selling" price index.

All the series have been adjusted to correspond with the January 1975 issue of IFS which changes the index base to 1970 = 100. The data for 1949 - 1974 has been collected from the CRA report and for 1975 - 1979 from the IFS and Bulletin of Statistics. Both these sources give identical estimates.

VI Production of Jet Engines:

Data for 1947 to 1968 were obtained from Aerospace Facts and Figures, and data for 1969 - 1975 has been collected from the CRA report.

Appendix C

Notes on Some Exogenous Variable Forecasts for 1979

DTURB

This variable was used to proxy the demand for gas turbines in uses other than jet engines. Since use of turbines for power generation has been increasing the dummy DTURB was assigned a value of 9 for the year 1979.

D545

This dummy was zero for 1979.

D6

This dummy was also zero for 1979.

D7

The dummy for political events in Zaire was assigned a value of 1 for 1979.

D8

The price of cobalt in 1979 was unusually high but there were no exogenous disturbances which could adequately account for it so this dummy was zero for 1979.

DHF

With the discovery of new welding process cobalt consumption in welding electrodes has been declining. Since this trend was expected to continue DHF was 1 for 1979.

DLEAD

Dummy was 1 for 1979.

DMA2

Dummy was 7 for 1979.

YJET

The data for the years 1975 to 1979 was collected from the forecasts of YJET made by Charles River Associates for their simulation experiment. (For details see CRA Econometric Model of the World Cobalt Industry, Nov. 1976.)

<u>Year</u>	<u>YJET</u>
1975	3280
1976	4419.257
1977	4308.464
1978	3836.304
1979	3364.144

YTV

The forecast for 1979 was obtained by first regressing YTV on YDUR for the years 1947 - 1972 and 1976 - 1978.

$$YTV = 17.7392 + 0.724605 YDUR$$

$$R^2 = 0.7408 \quad R^2(C) = 0.7312$$

$$F\text{-Statistic } (1,27) = 77.1674$$

Since, YDUR for 1979 was 146.3, YTV for 1979 was forecasted to be 123.75.

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