FORECASTING THE MARKET FOR MOLYBDENUM

by

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T-2657

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Mineral Economics).

Golden, Colorado

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ABSTRACT

The purpose of this thesis is to provide a simplified way of forecasting the market for molybdenum. Multiple regression and Box-Jenkins forecasting methods are used to forecast molybdenum production, consumption, and price. Descriptions of the forecasting methods used are given in the text of the thesis. Background information on both the world and U.S. molybdenum markets is provided, including their recent history and considerations for the future.

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ACKNOWLEDGEMENTS

The author appreciates all the time and effort that her thesis committee put into the preparation of this thesis. Committee members, Dr. Lynde O. Gilliam and Dr. Alfred Petrick, contributed their thoughts, suggestions, and a great deal of their time. Dr. Charles E. Lienert, my thesis advisor, willingly provided all the encouragement, wisdom, and support that I needed to see this effort through to completion. I cannot adequately thank him for all the work he put into this thesis.

Dr. Charles W. Berry, head of the Mineral Economics Department, offered his assistance and knowledge of the minerals industry in getting this thesis started.

Dr. Joseph C. Weber deserves special thanks for always managing to find the financial support necessary to keep me going, through both an HEW Mineral and Mining Fellowship and research assistantships.

The patience and perserverance of my typist, Linda Hughes, made this thesis's final form possible. Leanne Baker, whose fine eye edited these pages, deserves thanks for her assistance and for her friendship.

This thesis is dedicated to my mother,

Elsie M. Good,

and to the loving memory of my father,

Lowell H. Good,

whose wisdom, support, and

understanding made

my education possible.

CHAPTER 1

1.1 FORECASTING THE MARKET FOR MOLYBDENUM -- AN INTRODUCTION

The U.S. is the world's largest producer of molybdenum, a metal of strategic importance due to its wide use as an alloy in steels and cast irons. When used as an alloy, molybdenum improves hardenability, strength, toughness, and corrosion resistance. These properties make it a valuable additive to steels being used in construction, pipeline, railroad, and aerospace applications. Numerous metals, including tungsten, chromium, vanadium, columbium, and boron, can substitute for molybdenum in alloy steels; however, very little substitution takes place because molybdenum is cheaper, more readily available, and more versatile than the other metals. The chemical industry considers molybdenum to be an important catalyst, while the electronics industry values molybdenum metal because of its high melting point.

The demand for molybdenum grew throughout the 1970's, stimulating a great deal of investment in molybdenum exploration and development projects. World demand increased from 70,000 tons in 1972 to 101,600 tons in 1980 (Mining Journal, January 23, 1981, p. 50). Spot market prices rose

to over $30 a pound for molybdic oxide in 1979, the highest they have ever been. The outlook for molybdenum seemed exceptionally promising with several new primary molybdenum mines scheduled to begin production in the early 1980's. Growth rates for molybdenum consumption were predicted to be near 6 percent a year during the coming decade (Sutulov, Volume III, 1980, p. 248). Companies felt the molybdenum market would be able to absorb all of the new production.

Unfortunately, the forecasts for molybdenum's future were inaccurate. Spot prices for molybdic oxide fell from their all time high of over $30 a pound in 1979 to a low of $3.30 a pound in December 1981 (Metals Week, March 15, 1982, p. 3). Climax currently lists its molybdic oxide at $8.50 a pound, but the price is "nominal", meaning that no appreciable amount of the metal is being sold at that price. Currently the dealer price for molybdenum ranges between $4.85 and $5.20 per pound (Metals Week, May 3, 1982, p. 5). All of the major producers have drastically reduced their 1982 production figures. AMAX's Climax and Henderson mines are operating at 45 percent capacity. Duval has cut back its 1982 production figures by 57 percent, Placer by 60 percent, and Noranda by 20 percent (Metals Week, April 19, 1982,

p. 8). These production cuts have done little to reduce producer stockpiles. A significant upturn in demand is needed to improve these conditions, but most forecasters do not see consumption rising before the end of 1982.

In a little over two years the molybdenum market has gone from one extreme to the other, from the best it has ever been to severe depression. Forecasts from both time periods seem to be naive, in that whatever was happening in the market was expected to continue indefinitely. There did not seem to be a great deal of consideration given to the cyclicality of the metals market, or to the future of the economy as a whole. The purpose of this thesis is to try to develop a better method of forecasting the molybdenum market by using multiple regression and Box-Jenkins forecasting techniques. The methodology will be discussed more thoroughly at the end of this chapter, after background information has been presented.

1.2 A Brief History of the Molybdenum Market

The name molybdenum was derived from the Greek words "molybdos" and "molybdaena", which were used to describe any substance containing lead. Although these terms were applied to the minerals galena, graphite, and molybdenite, only galena (lead sulfide) actually contained lead. A great deal of this early confusion over the metal can be attributed to the fact that native molybdenum does not occur in nature because of its high reactivity. Obtaining molybdenum metal from molybdenite (molybdenum disulfide) requires high temperatures (2600^{o}C) and special reduction conditions which scientists did not achieve until the late eighteenth century. Karl Wilhelm Scheele, a Swedish chemist, was the first to identify molybdenite as molybdenite as molybdenum desulfide in 1778. J. J. Helm obtained impure metallic molybdenum from molybdic acid in 1782 (Sutulov, 1976, p. 39-41).

The first molybdenum ore produced was from the Knaben mine in Southern Norway during the mid-1800's; however, production from the mine was sporadic until 1895. High grade molybdenum-quartz veins were also being mined in Australia, Maine, and Washington during the same time period. In addition, molybdenum was being recovered from tungsten (wulfenite) ores in oxidized lead mines found

in Arizona and Mexico (Minobras, 1979, p. 1-4).

Although research into the physical properties of molybdenum was hindered by difficulties in obtaining the pure metal, molybdenum compounds were already being used in chemicals and dyes by the second half of the nineteenth century. Finally, in 1895 Henri Mossian succeeded in obtaining 99.98 percent pure molybdenum metal by utilizing an electric furnace. This allowed him to determine molybdenum's atomic weight and to study the other physical properties of the metal. Sanderson Steel Company began manufacturing a self-hardening molybdenum tool steel in 1898. This initial use of a molybdenum as an alloy failed because Sanderson did not know how to properly heat treat the material, which led to erratic performance by the tool steels. In 1900, Taylor and White, two U.S. metallurgists, demonstrated molybdenum high-speed tool steels at the Universal Fair in Paris. This demonstration promoted wider acceptance of molybdenum as an alloy and encouraged experimentation with the metal. The invention of the flotation recovery process by Francis E. Elmore of Great Britain in 1904 also encouraged the use of molybdenum. After the floatation process was developed it was no longer necessary to recover molybdenite through the expensive hand-sorting techniques, or by gravity techniques (Sutulov, Volume III, 1980, p. 178).

Even though all of these discoveries promoted the use of molybdenum, it remained for World War I to create the first significant demand for the metal. The demand for molybdenum was caused primarily by the shortage of tungsten, a necessary alloy in arms production. Molybdenum was used as a substitute for tungsten because of its relative abundance and significantly lower price, even though the results achieved with molybdenum alloys were not as favorable. The combined production of molybdenum from the U.S., Canada, Australia, and Norway reached two million pounds in 1918. Due to the increased demand, both the Climax mine in Colorado and the Questa mine in New Mexico were opened in 1918. The end of the first World War was disastrous for the molybdenum market because production of weapons ceased and large stockpiles of the metal existed. All the operating molybdenum mines closed (Minobras, 1979, p.1).

Brainerd Phillipson, a member of Climax's managment, began an intensive research program to develop peacetime uses for molybdenum. Molybdenum steels were tested by various automakers, beginning with Studebaker in 1920. The research paid off when the Society of Automotive Engineers approved some chromium-molybdenum steels for use in automobile production in 1925. The Climax mine reopened

in 1923, followed by the Questa mine in 1925; together these two mines dominated world production of molybdenum for decades. Climax's production reached three million pounds a year in 1929. In 1930, Watertown Arsenal discovered the necessary temperature ranges for heat treatment of molybdenum based high-speed steels. During the thirties, research showed that molybdenum improved strength, hardenability, and corrosion resistance. Molybdenum also performed well in conjunction with chromium, tungsten, nickel, and manganese. These discoveries led to an increase in the demand for molybdenum in structural steels, tool steels, and superalloys (Sutulov, 1976, p. 48).

Apart from the Climax based research, Anaconda made a significant contribution with its recovery of by-product molybdenum from the Cananea copper mine in northern Sonora, Mexico in 1933. By-product production from Cananea reached three million pounds in 1943. Kennecott Copper began producing by-product molybdenum from its Bingham Canyon mine in 1936. Bingham Canyon was often second only to Climax in terms of U.S. molybdenum production during the 1940's and 1950's. Other copper porphyries that began producing by-product molybdenum during this period include the El Teniente mine in Chile in 1939, and the Kounrad deposit in the U.S.S.R. in 1941 (Minobras, 1979,

p. 1).

By the onset of World War II, 89 percent of the world molybdenum production came from the U.S., with only slightly over 2 percent coming from the Axis countries. The demand for molybdenum swelled to 66 million pounds in 1942. Climax and Questa mines together supplied 85 percent of the U.S. production. Postwar demand dropped back to 20 million pounds in 1946; however, there was a significant difference between this drop in demand, and the one that had followed World War I. Climax Molybdenum had created a stable market for its product, and also controlled 75 percent of the world production. Since Climax controlled the market, it was able to prevent total collapse. Climax had also wisely invested a large part of its wartime profits into further research and development. Molybdenum's resistance to high temperature and stress made it essential in missile and rocket production, jet engines, transportation, drilling materials, and oil and gas pipelines (Sutulov, 1976, p. 53).

U.S. production has increased to meet the increasing demand for molybdenum; it reached 68 million pounds in 1960, 101 million pounds in 1970, and 150 million pounds in 1980. Until 1976, the two largest primary producers in the U.S. were still Climax and Questa. AMAX brought its Henderson

mine into production in 1976, and by 1978 Henderson was second only to Climax in molybdenum output (Minobras, 1979, p. 2).

Molybdenum supply has changed a great deal from World War II; approximately half of the present molybdenum production is a by-product from copper and tungsten mining. By-product molybdenum from the Arizona porphyry copper mines first became a significant factor in the late 1960's. By the mid-1970's Arizona was second only to Colorado in terms of molybdenum production. By-product molybdenum production from Chile and the U.S.S.R. increased substantially during this period. The Toquepala mine in Peru also began to recover molybdenum in the late 1960's.

Canada entered the molybdenum market in 1965 with two primary molybdenum mines in British Columbia, Endako and Bass Mountain. Canada is now the second largest producer of molybdenum in the world.

Ninety-nine percent of the world's molybdenum is produced by four countries, the U.S. (60 percent), Canada (15 percent), Chile (13 percent), and the U.S.S.R. (11 percent). A detailed mine-by-mine survey of operating molybdenum mines will be presented in Chapter 2, along with a review of current prospects (Minobras, 1979, p. 2).

1.3 Molybdenum's Uses

The demand for molybdenum developed due to its alloying properties and its use in chemical compounds, not for the properties of the metal itself. Approximately 80 percent of the world's demand for molybdenum can be attributed to its use as an alloy, 8 percent to its use in chemicals, 5 percent is used as molybdenum metal and the final 7 percent is used in cast iron and steel mill rolls along with other uses (see Table 1.1). In this table, the "alloy steel" category refers to structural steel which includes both high-strength low alloy steels and carbon steels. Carbon steels are not technically considered to be alloy steels because they often contain alloying metals in unspecified amounts. Alloy steels are defined by the amount of alloying metals they contain, while carbon steels are classified by their performance.

TABLE 1.1
1980 Consumption of Molybdenum
in Non-communist Countries by Major Industrial Categories

Use	Percent
Alloy Steels	46
Stainless Steels	21
Tool Steels	10
Cast iron and steel mill rolls	6
Super and Special alloys	3
Molybdenum metal	5
Chemicals	8
Other	1
TOTAL	100

SOURCE: Engineering and Mining Journal, March 1981, p. 108-109.

Molybdenum's effects as an alloy include improved hardenability, resistance to temper embrittlement, improved strength at both elevated temperatures and high speeds, and better resistance to corrosion. The most important effect caused by adding molybdenum to steels, or cast irons, is improved hardenability. Molybdenum makes it possible to heat treat these materials to improve their strength and lengthen their life. Molybdenum also helps prevent temper embrittlement, or the loss of strength and hardness due to heating. With a concentration of greater than 0.75 percent molybdenum, not only will temper embrittlement be avoided, but a secondary hardening effect will be achieved. Molybdenum improves wear resistance and hardness in high-speed steels at elevated temperatures and rapid speeds. Stainless steels need molybdenum to help provide resistance to corrosion and to improve strength at high temperatures. Molybdenum can also be added to gray and ductile cost irons without changing their casting characteristics (Sutulov, Volume III, 1980, p. 41).

Molybdenum's properties that make it important for chemical uses include its ability to change valency states, its color in various chemical compounds, and its lubricating abilities. Molybdenum is useful as a catalyst

to remove sulfur from cobalt, nickel, iron, and vanadium because of its ability to change valency states. Pigments that contain molybdenum are used in coloring plastics, ceramic glasses and printer's ink. Pure molybdenite, molybdenum disulfide, is used as a lubricant. The weak bonds between molybdenum atom layers in molybdenite, which give the mineral its perfect cleavage and its thermal resistance, make it an excellent lubricant (Sutulov, Volume III, 1980, p. 274-275).

Only the United States keeps accurate records of molybdenum consumption by end use and form; the data for 1980 is listed below in Table 1.2. Alloy steels are defined to be all steels which contain a specified amount of additive metal.

As was previously mentioned, carbon steels are classified by their performance, not their composition. They frequently contain unspecified amounts of additives including molybdenum, tungsten, and vanadium. Molybdenum is generally added in small quantities (less than a pound per ton), so that even though carbon steels comprise 90 percent of the raw steel output (Sutulov, Volume III, 1980, p. 272), they account for only 4.8 percent of the U.S. molybdenum consumption.

Stainless steels are used in chemical and petroleum

TABLE 1.2
U.S. Consumption of Molybdenum by End Use and Form

	Molybdic Oxide	Ferromolybdenum[1]	Soluble Molybdates	Other[2]	TOTAL
Steel:					
Carbon	2,390	133	---	31	2,554
Stainless and heat resisting	6,582	1,186	---	140	7,878
Full alloy	17,340	2,123	---	35	19,498
High-strength,low-alloy	1,357	311	---	9	1,677
Tool	2,641	599	---	36	3,236
Cast irons	476	2,460	---	132	3,068
Superalloys	1,906	446	---	2,174	4,526
Alloys (excludes steels and superalloys):					
Welding and alloy hard-facing rods and materials	-----	305	---	47	352
Other alloys3	215	324	---	185	724
Mill products made from metal powder	-----	---	---	4,222	4,222
Chemical and ceramic uses:					
Pigments	397	---	268	-----	665
Catalysts	2,585	---	W	77	2,662
Other	12	---	17	1,033	1,062
Miscellaneous and unspecified	179	137	483	342	1,141
TOTAL	36,080	7,954	768	8,463	53,265

W Withheld to avoid disclosing company proprietary data.

1 Includes calcium molybdate.

2 Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

3 Includes magnetic and nonferrous alloys.

SOURCE: 1980 Minerals Yearbook, U.S. Bureau of Mines, 1981, p. 577.

refining, food processing, pharmaceuticals and for any other industrial application that requires resistance to corrosion. Corrosion resistance is primarily due to the presence of chrome, hence stainless steels often contain molybdenum and nickel in addition to their major additive chrome. Stainless steel is second only to full alloy steel in terms of molybdenum consumption; it accounts for 14.8 percent of the U.S. demand.

Full alloy steels are steels which contain greater than 0.3 percent molybdenum. It is the largest category in U.S. consumption containing 36.6 percent of the molybdenum used during 1980. Full alloy steels have better strength, hardenability, abrasion, and corrosion resistance which makes them desirable for ship building and construction. They are also used extensively in the transportation and machinery industries where engine parts need to be strong and abrasion resistant. Full alloy steels are important for mining and milling equipment where abrasion resistance is critical (Sutulov, Volume III, 1980, p. 273). It is interesting to note that it is often difficult to find crushing equipment for sample preparation that does not use molybdenum steel. It is possible to inadvertently increase assaying results for a copper or molybdenum prospect by using crushing plates that contain molybdenum.

High - strength low-alloy (HSLA) steels are defined to be steels that contain less than 0.3 percent molybdenum. One of the major applications for HSLA steels is for oil and gas pipelines. Molybdenum makes it possible to use thinner walled pipes while improving corrosion resistance, strength, and toughness.

Tool steels, or high speed steels, comprise 3.1 percent of the molybdenum demand. Tool edges must be able to maintain hardness at high temperatures (600 - 700^{o}C). Molybdenum's effectiveness in this application is demonstrated by the fact that 90 percent of high speed steels contain molybdenum (Sutulov, Volume III, 1980, p. 274). Molybdenum has an additional advantage over tungsten for tool steels in that it only weighs half of what tungsten does.

Aside from its use in steels as an alloying metal, molybdenum is also used in cast irons and superalloys. Molybdenum improves the properties of cast iron without changing its casting characteristics. It increases cast iron's strength at high temperatures, and helps prevent sharp edges from chipping. Superalloys are used for applications that require corrosion and temperature resistance along with good wear resistance. They are used in jet engines, rockets, and other aerospace materials.

Superalloys are also used in foundries, retorts, and furnaces. The molybdenum content of superalloys varies between 3 and 20 percent; this variation depends on the amount of other alloying agents present, like chrome, cobalt, and nickel (Sutulov, Volume III, 1980, p. 273-275). Superalloys make up 8.5 percent of the U.S. demand for molybdenum, while cast iron comprises 5.8 percent.

Molybdenum metal has a high melting point, strength at high temperatures and excellent heat resistance. It is primarily used as filament supports in incandescent light bulbs; it is also used for heating elements in different types of furnaces. A relatively new use for molybdenum metal is in semiconductors. Molybdenum metal comprises 7.9 percent of the U.S. demand for molybdenum.

The chemical uses for molybdenum include pigments, catalysts, and lubricants. Catalysis is the fastest growing of the three applications. Since molybdenum easily changes its valency state, it is quite useful in exchanging sulfur and oxygen. This makes it important in desulfurization, dehydrogenation, denitrification, and formalin manufacturing (Sutulov, Volume III, 1980, p. 275). Chemical uses currently make up 8.3 percent of the molybdenum consumption.

1.4 Molybdenum Products

There are seven major commercial forms in which molybdenum is sold: molybdenite concentrate, technical molybdic oxide, pure molybdic oxide, ferromolybdenum, sodium molybdate, ammonium molybdate, and molybdenum metal. Molybdenum concentrate is the initial molybdenum product to appear on the market. The U.S. National Stockpile Specifications place limits on impurities allowed in concentrates that the U.S. will purchase, or maintain, in their stockpile. The concentrate market follows those specifications rather closely in its pricing procedures. Climax concentrate, which contains at least 90 percent molybdenum disulfide and almost no copper, is the basis for primary production concentrate pricing. Copper is the most objectionable impurity to steel producers, so concentrates containing larger amounts of copper are charged a penalty. Naturally, by-product molybdenite concentrate will be of a lower grade than Climax concentrate, so 85 percent molybdenum disulfide is used as the reference point for secondary production pricing. Standard purity concentrates contain less than 0.5 percent copper. Any concentrate that contains greater than 0.5 percent copper is termed off-grade and must pay a significant penalty in

terms of price. Molybdenite concentrate that is to be used as a lubricant is upgraded until it reaches between 98 and 99 pure molybdenum disulfide (Sutulov, Volume III, 1980, p. 190).

Technical molybdic oxide is the principle commercial form for molybdenum. Nearly 97 percent of all molybdenite concentrate is converted to technical molybdic oxide before further use (Sutulov, Volume III, 1980, p. 1980). Molybdenite concentrate is roasted to remove the sulfur, and then bagged, put in drums, or made into briquettes for shipping. There is currently a 9 percent difference in price per pound between molybdenite concentrate and technical molybdic oxide to compensate for processing costs and metallurgical losses (Metals Week, May 3, 1982, p. 5). The U.S. National Stockpile specifications limit copper content to 0.5 percent and require that molybdic oxide contain at least 60 percent molybdenum. Again, pricing policies are tied to purity and high copper molybdic oxides are penalized.

Pure molybdic oxide contains 99.95 percent molybdic oxide, or 66.6 percent molybdenum. It is used to produce chemicals and molybdenum metal. Pure molybdic oxide is obtained by reprocessing and upgrading technical grade molybdic oxide. Molybdenum metal is obtained by reducing

the pure molybdic oxide. It is then made into bars, rods, wires, sheets, or ingots depending on what its future application will be.

Ferromolybdenum was once the most common way of adding molybdenum to steel; however, currently it is only used in high-alloy steels because of its higher cost per pound than technical grade molybdic oxide. The price differential of nearly 10 percent is due to the difference in processing costs. High-alloy steels generally use technical molybdic oxide until 1 percent molybdenum is reached, then ferromolybdenum is used to supply the rest of the desired molybdenum content (Sutulov, Volume III, 1980, p. 191).

Both of the common forms of soluble molybdates, ammonium molybdate and sodium molybdate, are used in the preparations of other chemical products. Ammonium molydate is generally produced from pure molybdic oxide because it is used for preparation of catalysts and reagents. Sodium molybdate is generally produced using technical grade molybdic oxide because it is used in pigments, fertilizers and decorative coatings which do not require high purity levels. Numerous other chemicals containing molybdenum are available through chemical companies or Climax itself (Sutulov, Volume III, 1980, p. 191).

1.5 Prices for Molybdenum Products

As was discussed in the previous section, prices for molybdenum products are based on their molybdenum content and their purity. Of the seven major commercial forms, the three products that are heavily traded on the international market are molybdenite concentrate, technical molybdic oxide, and ferromolybdenum. All three products use Climax molybdenite concentrate price as their base, since Climax has traditionally controlled molybdenum production. Current prices for the three products are listed below in Table 1.3.

TABLE 1.3
Molybdenum Product Prices

Product	Price($/lb)
Climax Concentrate*	7.90
By-product Concentrate	3.75 - 4.20
Climax Oxide*	6.85 - 8.50
Export Oxide	5.52 - 8.77
Dealer Oxide	4.85 - 5.20
Export Ferromolybdenum	
Climax*	7.75 - 9.40
Dealer	5.90 - 6.25

*Note: Climax list prices are "nominal", meaning that the producer is publishing these prices for the products even though there is no appreciable amount of the metal being sold at these price levels.

SOURCE: Metals Week, May 3, 1982, p. 5.

There is currently a multi-level pricing system for molybdenum products consisting of domestic producer prices, export producer prices, and dealer prices. Producer prices include both primary and by-product producers; they generally follow the lead set by Climax. In periods of high demand there is little difference in price between Climax concentrate and by-product concentrate; with the current situation of large stockpiles and over production, Climax concentrate price ($7.90/lb) is twice the price of by-product concentrate ($3.75 - 4.20/lb). By-product producers can afford to cut their prices because they do not have to support the substantial fixed costs associated with the large capital investments that the primary producers have. Producer prices were split into domestic and export prices during the world-wide shortage of molybdenum in 1978 and 1979. Although the U.S. was the world's largest producer of molybdenum, many U.S. buyers were being forced to go to the spot market to purchase molybdenum products. They actually had to import molybdenum in a number of instances. An agreement was reached between producers and consumers that two prices would exist, domestic and export, so that U.S. buyers would not be adversely influenced by the world market. During 1979, a year when demand for molybdenum was high, there was

a 50 to 70 percent price differential between domestic and export prices. Currently, export prices are at, or below, domestic prices because of the large oversupply of molybdenum.

Dealers control only a very small portion of the molybdenum market; however, their prices are often used as an indication of the current state of the market. When demand was high in 1979, spot prices reached three to four times the Climax price. Currently the dealer prices for both technical grade oxide and ferromolybdenum are little more than half the current Climax price.

Of the three products, technical grade molybdic oxide is the most widely traded form. Molybdic oxide is sold for direct use in steelmaking and for conversion to chemical uses. For this forecasting problem, it is the domestic producer price for technical grade molybdic oxide that will be forecast, along with the future supply-demand situation for molybdenum.

1.6 Forecasting Techniques

Both multiple regression and Box-Jenkins forecasting techniques will be used to forecast production, consumption, and price for molybdenum. The Box-Jenkins method will be used for medium-range forecasts, i.e., forecasts that range up to two years in the future. Multiple regression will be used for the long-range forecasts, or for forecasts more than two years in the future.

Box-Jenkins is a very effective method for forecasting complex time series when a variety of patterns exist in the data. The method uses only the variable being forecast to determine what underlying patterns exist. Box-Jenkins provides statistical information on the different models assumed and by analyzing this information it is possible to choose the best forecasting model for the data. This process will be described in greater detail when the first models are presented.

Multiple regression assumes that the quantity being forecast, the dependent variable, can be predicted by its relationship with other independent variables. Multiple regression is a statistical method which provides measures of accuracy and significance for different hypothesized models. The independent variables selected

to help predict molybdenum's price, supply, and demand should have a direct effect on the molybdenum market. Although it is critical to correctly use the forecasting techniques, it is equally important to relate them to the actual market situation.

Since the U.S. is the world's largest producer of molybdenum, it keeps accurate monthly records of production, consumption, and price. Data on the world market, however, is only available on a yearly basis. Both the U.S. supply-demand situation, and the world supply-demand situation will be forecast using the best information available. All variables that will be used in the analysis, and the sources for the data, will be described before the first forecasting models are presented.

CHAPTER 2

2.1 FORECASTING MODELS FOR MOLYBDENUM SUPPLY

AN INTRODUCTION

Forecasting models that will be used to predict molybdenum production are presented in this chapter. The variables that will be examined in forecasting the market for molybdenum, and the sources for the data, are described in detail in Appendices A, B, and C. The data that will be used to create the forecasting models are listed in Appendices D, E, and F. Variables used for specific models will be described as they are presented in the text of the thesis.

Before presenting the models that will be used to forecast molybdenum production, a brief explanation of Box-Jenkins and multiple regression forecasting methods will be given. The recent history of molybdenum production will be reviewed; current production figures will also be examined.

The forecasting models will then be presented. After the models have been presented, potential mine development projects and exploration prospects will also be reviewed.

2.2 Box-Jenkins Forecasting Method

The Box-Jenkins forecasting method is different from most types of forecasting methods because it does not require the user to assume a fixed pattern in the data. Information about the variable being forecast is provided to the user by the autocorrelation coefficients and partial autocorrelation coefficients. The formulas used to calculate the autocorrelation coefficients and partial autocorrelation coefficients are quite complex; explaining them here would diverge from the main thrust of this thesis. The reader is referred to either Box and Jenkins' book on time series analysis, or Granger and Newbold's book on forecasting time series, referenced at the end of this section.

By studying the patterns in both the autocorrelation and partial autocorrelation coefficients, it is possible to indentify a tentative forecasting model. Three general categories of models exist: autoregressive (AR), moving average (MA), and a mixed model containing both autoregressive and moving average portions (ARMA). Variations on these types of models can be used to describe virtually any kind of time series data. Once a tentative model has been identified, Box-Jenkins provides statistical information

on the model which allows the user to decide if it is adquate. If the model is inadequate, the user can try a different model.

The initial requirement for using the Box-Jenkins forecasting technique is that the data must be stationary, or without trend. Differencing is usually used to convert a non-stationary time series to a stationary one. Differencing subtracts values in a time series from previous values, thereby removing the trend; the differenced values are used to form a new stationary time series. Time series data often contain seasonal patterns along with period to period patterns. Long differencing, or differencing by the length of seasonality, lets the user forecast longer, repetitive patterns in the data that occur seasonally. Again, patterns in the autocorrelation and partial autocorrelation coefficients make it possible to tentatively identify seasonal models and to test them statistically.

Once a satisfactory model has been identified, it is relatively easy to forecast the periods ahead. Box-Jenkins forecasting also allows the user to put statistical confidence intervals on the values being forecast.

This is a brief explanation of a very complex forecasting technique. For additional information on Box-Jenkins

methodology the reader is referred to Makridakis and Wheelwright's Forecasting Methods for Management (1980), and their Forecasting Methods and Applications (1978). A more detailed mathematical treatment can be found in either Forecasting Economic Time Series (1977) by Granger and Newbold, or Time-Series Analysis Revised Edition (1976) by Box and Jenkins.

The Sibyl/Runner Interactive Forecasting (DEC 10 and DEC 20 Version 3.0 (July 80)) package, owned and supported by Applied Decision Systems of Lexington, Massachusetts, will be used to forecast the Box-Jenkins models.

2.3 Multiple Regression Forecasting Method

As was previously stated, multiple regression assumes that the quantity being forecast, the dependent variable, can be predicted by means of its relationship with other independent variables. Multiple regression can handle any type of causal relationship between the dependent and independent variables, as long as the regression coefficients are linearly related to the dependent variable. The regression line is of the general form:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \ldots + u \qquad (2\text{-}1)$$

where

Y = dependent variable being forecast,

$\alpha, \beta_1, \beta_2, \beta_3, \beta_4$ = regression coefficients.

X_1, X_2, X_3, X_4 = independent variables, and

u = residual term, or that portion of Y which is not explained by the independent variables.

Regression coefficients for the independent variables are determined by using the method of least squares which seeks to minimize the mean squared error (MSE) between actual values and forecast values. The formula used to calculate the MSE is:

$$MSE = \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{n} \qquad (2\text{-}2)$$

where

MSE = mean squared error,

Y_i = actual values for the dependent variable,

$\hat{Y}_i$ = forecast value for the dependent variable, and

n = number of data points.

Once a regression line has been fitted to the data using the method of least squares, statistical information is provided to help determine the significance of the equation as a whole, and the significance of the individual regression coefficients.

One measure of the predictive ability of the regression

equation is the coefficient of determination, R^2. If it is stated that $R^2 = .95$, this indicates that 95 percent of the total variation of the dependent variable (Y) around its mean is jointly explained by the independent variables. It is a measure of how well the regression line describes the data. If $R^2 = 1$, the regression line perfectly fits the data points; however, if $R^2 = 0$, the regression line does not explain any of the dependent variables variation around its mean. The formula used to calculate the coefficient of variation is:

$$R^2 = \frac{\sum_{i=1}^{n} (\hat{Y}_i - \bar{Y})^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2} \qquad (2\text{-}3)$$

where

R^2 = coefficient of determination,

$\hat{Y}_i$ = actual value for the dependent variable,

Y_i = forecast value for the dependent variable,

$\bar{Y}$ = mean of the dependent variable, and

n = number of data points.

The coefficient of determination is a monotonic non-decreasing function of the number of independent variables. The more independent variables used to describe the dependent variable, the larger R^2 will be. To be able to

compare regression equations with different numbers of independent variables, it is necessary to calculate $\bar{R}^2$, which is R^2 adjusted for the number of independent variables. The formula used to calculate $\bar{R}^2$ is:

$$\bar{R}^2 = 1 - (1 - R^2) \frac{n - 1}{n - k} \qquad (2\text{-}4)$$

where

$\bar{R}^2$ = coefficient of determination adjusted for the number of independent variables,

R^2 = coefficient of determination,

n = number of data points, and

k = number of regression coefficients to be estimated.

One of the inherent assumptions of multiple regression is that the residuals, or error terms, are independent of each other. If the residuals are not independent of each other, if there is still a pattern in the residuals, serial correlation is said to exist. Serial correlation is serious because it implies that the wrong functional form has been used in the regression equation, or that an important independent variable has been left out. Two methods can be used to test for serial correlation; examining a plot of the residuals, or computing the Durbin-Watson statistic. The formula for computing the Durbin-Watson statistic is:

$$d = \frac{\sum_{i=1}^{n} (\hat{u}_i - \hat{u}_{i-1})^2}{\sum_{i=1}^{n} \hat{u}_i^2} \qquad (2\text{-}5)$$

where

d = Durbin-Watson statistic,

$\hat{u}_i$ = estimated error term, and

n = number of data points.

It is then possible to test for serial correlation by comparing the computed Durbin-Watson statistic with table values.

Another inherent assumption of multiple regression is that multicollinearity, or a linear relationship between independent variables, does not exist. When multicollinearity exists, it becomes impossible to isolate the effect that any one independent variable has on the dependent variable. If multicollinearity exists, the coefficient of determination will be large, but few or none of the individual regression coefficients will be statistically significant. By using the t-test, it is possible to determine if each regression coefficient is significantly different from zero, or if its value simply occured by chance. The formula used to compute the t-ratio for each of the estimated regression coefficients is:

$$t = \frac{\hat{b}}{\hat{\alpha}_{\hat{b}}} \qquad (2\text{-}6)$$

where

$\hat{b}$ = estimated regression coefficient, and

$\hat{\alpha}_{\hat{b}}$ = standard deviation of the estimated regression coefficient.

The t-test is then conducted by comparing the calculated t-ratio with known values of the t-distribution.

Using multiple regression as a forecasting technique forces the user to determine which factors influence the dependent variable. Once these factors, or independent variables, have been identified, it is necessary to forecast the independent variables to determine the future value of the dependent variable. Multiple regression also allows statistical confidence intervals to be determined for the forecast values.

For a more detailed explanation of multiple regression, the reader is referred to Makridakis and Wheelwright's Forecasting Methods for Management (1980) and their Interactive Forecasting (1978), or to Forecasting Methods (1971) by Chisholm and Whitaker.

The Minitab (Release 81.1) statistical computing system, written by Thomas A. Ryan, Jr. of Penn State University, will be used to forecast the regression models.

2.4 Recent History of Molybdenum Production

World production of molybdenum grew from 178 million pounds in 1970 to 238 million pounds in 1980 (Minerals Yearbook, 1971, p. 758 and 1980, p. 583). It is important to note that U.S. dominance of the molybdenum market declined significantly between 1960 and 1970. In 1960 the U.S. produced 76 percent of the world's molybdenum; however, by 1970, it produced only 62 percent of the world's molybdenum (Minerals Yearbook, 1961, p. 932 and 1970, p. 758). This change was due to the increase in Canadian and Chilean production during the mid-1960's (Sutulov, 1981, p. 75). The U.S. has maintained approximately the same percentage of world output since 1970; the U.S. produced 63 percent of the world's molybdenum in 1980 (Minerals Yearbook, 1980, p. 583). The percentage has not changed significantly since 1970 because U.S. producers have been adding production capacity as rapidly as foreign producers have.

It is interesting to compare different countries' cumulative molybdenum production, production capacity, and total molybdenum resources. The cumulative figures through 1981 are shown in Table 2.1 below:

Table 2.1

World Molybdenum Production, Production Capacity, and Resources

Country	Total Cumulative Production (in percent)	Production Capacity per Year (in percent)	Total Resources (in percent)
United States	66.6	58.3	45
Canada	9.5	16.8	7
Chile	7.6	10.4	35
U.S.S.R.	7.6	8.6	8
Total Others	8.7	5.9	5
Peru	N/A	2.3	N/A
China	N/A	1.4	N/A
Mexico	N/A	1.3	N/A
All Others	N/A	.9	N/A
TOTAL	100.0	100.0	100
TOTAL (million of pounds)	4,630	306	11,023

N/A means that information on that country was not available.

SOURCE: Sutulov, Intermet Molybdenum Yearbook 1982, p. 7 - 8.

The U.S., with its 45 percent of world molybdenum resources, should be able to maintain its share of the world market. The U.S.S.R.'s production is also consistent with its resources. Future production figures for Canada and Chile will probably change. Canada can currently produce

up to 16.8 percent of the world's molybdenum, but only has 7 percent of the world's resources. Chile has 35 percent of the world's resources, but can only produce 10 percent of the world's molybdenum. Chile will probably become second only to the U.S. in terms of molybdenum production in the near future.

U.S. production grew from 111 million pounds in 1970 to 151 million pounds in 1980 (Minerals Yearbook, 1971, p. 751 and 1980, p. 573). In 1972, U.S. molybdenum stocks reached a high of 45 million pounds; yearly production at that time was around 112 million pounds (Minerals Yearbook, 1973, p. 779). These large producer stockpiles were due to the slowdown in the U.S. economy after the Vietnam war ended. A major increase in the demand for molybdenum came in 1973-74 in response to the energy crisis; U.S. producers could not initially keep up with the new demand. The U.S. government eased the situation by liquidating the stockpile of 45 million pounds of molybdenum between 1973 and 1975 (Sutulov, 1981, p. 131). Selling the stockpile was due to a change in government policy; the government felt that there was no point in stockpiling molybdenum, since U.S. production was more than adequate to cover the country's needs in a time of war. Producer stocks dropped from 45 million pounds in 1972 to 9 million pounds in 1976; they

remained at 9 million pounds until 1979 (Minerals Yearbook, 1973, p. 779 and 1980, p. 573).

U.S. producer stocks grew from 9 million in 1979 to 35 million pounds in 1981 (Mineral Industry Survey for Molybdenum, February 1982, p. 1). With record high prices for molybdenum in 1979, producers were encouraged to invest in molybdenum properties. The molybdenum shortage which drove dealer oxide prices to over $30 a pound was primarily caused by the combination of a Canadian mine strike and increased exports to Soviet bloc nations; the 1979 molybdenum shortage will be explored in greater detail in Chapters 2 and 3. The large increase in investment in 1979 led to increased production capacity not only in the U.S., but world-wide. World molybdenum production capacity in 1982 on a mine-by-mine basis is listed in Table 2.2. Production capacity is divided by country and company.

In 1980, world molybdenum production was approximately 80 percent of the world mine production capacity. This percentage has dropped significantly in 1981 and 1982; growing stocks of molybdenum and low copper prices have decreased operating mine production, or closed the mine altogether.

In December of 1981, all major North American molybdenum producers announced cutbacks in their 1982 production figures. AMAX announced a 20 percent cut, Noranda announced

Table 2.2

World Molybdenum Mine Production Capacity in 1982

	Mine Producing Capacity (in thousands of pounds of molybdenum per year	Expected Mine Life (years)
United States		
AMAX		
Climax*	50,706	31
Henderson*	55,115	35
Pennzoil (Duval)		
Sierrita	15,983	16
Mineral Park	3,748	7
Esperenza	1,984	8
Sohio (Kennecott)		
Utah Copper	12,125	42
Chino	551	130
Ray	771	99
ARCO (Anaconda)		
Twin Buttes	4,409	35
Tonapah	12,125	15
Newmont		
San Manuel	3,307	70
Asarco		
Mission	1,764	50
Silver Bell	331	20
Amoco (Cyprus)		
Bagdad	3,307	20
Pima	1,984	14
Cities Service		
Pinio Valley	881	77
Phelps-Dodge		
Morenci	551	120
Ajo	772	N/A

Table 2.2 (continued)

World Molybdenum Mine Production Capacity in 1982

	Mine Production Capacity (in thousands of pounds of molybdenum per year)	Expected Mine Life (years)
Hudson Bay		
Inspiration	396	300
Union Carbide		
Pine Creek	264	8
U.S. TOTAL	171,074	
Canada		
Placer		
Endako*	13,889	27
Gibraltar	772	20
Noranda		
Brenda	7,055	13
Gaspe	3,968	20
Boss Mountain*	1,323	8
Granisle	397	8
Utah International		
Island Copper	2,205	20
AMAX		
Kitsault*	8,818	30
RTZ		
Lornex	5,952	23
Teck		
Highmont	6,614	10

Table 2.2 (continued)

World Molybdenum Mine Production Capacity in 1982

	Mine Production Capacity (in thousands of pounds of molybdenum per year)	Expected Mine Life (years)
Billiton		
Mt. Pleasant	331	20
CANADA TOTAL	51,324	
Chile		
Codelco		
El Teniente	5,511	200
Chuquicamata	20,944	133
El Salvador	2,866	37
Andina	1,102	64
CHILE TOTAL	30,423	
Peru		
Southern Peru Copper		
Toquepala	1,984	70
Cujone	1,984	50
PERU TOTAL	3,968	
Mexico		
Frisco		
Cumobabi	3,968	N/A
MEXICAN TOTAL	3,968	

Table 2.2 (continued)

World Molybdenum Mine Production Capacity in 1982

	Mine Production Capacity (in thousands of pounds of molybdenum per year)	Expected Mine Life (years)
Bulgaria	4400	N/A
China	2,425	N/A
Japan	220	N/A
Korea	441	N/A
Mongolia	1,102	N/A
Philippines	772	N/A
U.S.S.R.	27,117	N/A
Yugoslavia	1,323	N/A
WORLD TOTAL	294,597	

*Denotes a primary molybdenum mine; all others by-product or co-product mines.

N/A means the information was not available.

SOURCE: Sutulov, Molybdenum Market Study 1981, p. 80 - 82, p. 93, and p. 120 - 122.

a 15 percent cut, Placer announced a 20 percent cut in production at Endako, Canada's largest molybdenum mine, and Duval announced a shutdown of all of its molybdenum operations for 3 months (Metals Week, December 21, 1981,

p. 3). By March of 1982, Placer had decided to cut its 1982 production figures by 60 percent, and Duval estimated that its 1982 molybdenum production would be 57 percent below its 1981 production (Metals Week, March 15, 1982, p. 3). AMAX announced an additional 20 percent cut in April of 1982 (Metals Week, April 19, 1982).

AMAX finally decided in late June to close both Climax and Henderson for five weeks starting July 5, 1982 (Colorado Transcript, June 24, 1982, p. 1). There is a great deal of speculation in the mining industry as to whether they will re-open in five weeks as scheduled.

The slump in the copper market has also caused many of the by-product producers to drastically cut production, or to close. In December of 1981, Asarco decided to shut its Silver Bell mine, and to shutdown Mission for a month. Phelps-Dodge announced it was cutting its 1982 production figures by 20 percent, Anaconda announced a 46 percent cut at Anamax, Cyprus Pima announced a 3-month 43 percent cut, and Bethlehem Copper closed its molybdenum circuit (Metals Week, March 15, 1982, p. 3). Kennecott announced that it would reduce its output by 35 percent in late March (Metals Week, March 22, 1982, p. 1).

Phelps-Dodge closed all of its copper mines for a month, beginning April 17, 1982; however, it had not

reopened by the end of June (Metals Week, April 12, 1982, p. 1). Many of the other American copper producers followed Phelps-Dodge's lead; Anaconda closed its main Berkeley mine at Butte on April 23, 1982 (Metals Week, May 3, 1982, p. 1), Cyprus Pima shut on June 4, 1982 (Metals Week, May 31, 1982, p. 7), and Cities Service extended a two-week vacation shutdown at its Pinto Valley mine to five weeks beginning June 27, 1982 (Metals Week, June 7, 1982, p. 1). Metals Week quoted an analyst as saying, "Producers won't reopen mines until copper prices really recover-until they can make money taking metal out of the ground." (Metals Week, June 7, 1982, p. 1). With free market copper prices below 60¢ a pound, it is doubtful that the closed copper mines will reopen in the next few months (Metals Week, June 14, 1982, p. 7).

The effect that these production cuts will have on 1982 world molybdenum production remains to be seen; however, the percentage of world production to world production capacity will be well below 1980's 80 percent.

Even with all of this current excess molybdenum mine production capacity, 3 new molybdenum mines are scheduled to begin production in 1983-84; they are listed in Table 2.3. These 3 mines will provide an additional 45 million pounds per year in production capacity.

Table 2.3

Molybdenum Mine Development Projects

	Production Begins	Mine Production Capacity (in thousands of pounds of molybdenum per year)	Expected Mine Life (years)	Estimated Cost (millions of dollars)
United States				
Union (Molycorp) Goat Hill*	1983	20,000	15	200
Amoco (Cyprus) Thompson Creek	1983-84	20,000	26	330
Mexico				
Mexicana La Caridad	1983	4,850	N/A	19
TOTAL NEW CAPACITY		44,850		

*Denotes primary molybdenum mine; all others are by-product, or co-product mines.

N/A means the information was not available.

SOURCE: Sutulov, Intermet Molybdenum Yearbook, 1982, p. 333.

2.5 Regression Models for Forecasting Molybdenum Production

Numerous regression equations were run for each dependent variable to determine which equation best described the quantity being forecast. Five statistical functions were examined for each regression equation, the t-statistic, the F-statistic, R^2, $\bar{R}^2$ (R^2 adjusted for the degrees of freedom), and the Durbin-Watson d-statistic. The best statistical model was defined to be the equation with the highest $\bar{R}^2$ value that did not exhibit either multicollinearity or serial correlation, and whose regression coefficients, and the entire equation, were statistically significant.

Once the best statistical model had been chosen, it was examined using economic theory concerning the relationships between price and quantity of complementary and substitutable goods. If the model made both statistical and economic sense, it was chosen as the best available model for the quantity being forecast. These selection criteria were used for all of the multiple regression models presented in this thesis.

The variables that were examined in the regression analyses, and the sources for the variables, are described in detail in Appendices A and B. The data that were used in the formulation of the regression equations are listed in

Appendices E and F.

The regression equation which best describes world molybdenum production is:

$$Y = -34856 + 901.3(\text{Copper Producer Price}) + 226.7\ (\text{World Steel Production}) \quad (2\text{-}7)$$

t-statistics: $a = -3.57$ $b_1 = 3.28$ $b_2 = 6.73$

$R^2 = 95.9$

$\bar{R}^2 = 95.5$

Durbin-Watson statistic = 1.05

Both independent variables, copper producer price and world steel production, are directly related to world molybdenum production. As copper prices rise, copper production will also rise. This will cause an increase in molybdenum production because approximately 40 percent of the world's molybdenum production is a by-product from copper mining (Duval, 1981, p. B29). Although speciality steels, the largest use for molybdenum, are only a fraction of total world steel output, increases or decreases in speciality steel production generally parallel total raw steel output.

The regression equation which best describes U.S. molybdenum production is:

$$Y = -7955 + 536.5\ (\text{U.S. Defense Spending}) + 2.069\ (\text{Alloy Steel Production}) + 7.46\ (\text{Domestic Oil Demand}) \quad (2\text{-}8)$$

t-statistics: $a = -1.30$ $b_1 = 5.16$ $b_2 = 2.13$ $b_3 = 2.35$

$R^2 = 95.1$

$\bar{R}^2 = 94.5$

Durbin-Watson statistic = 1.65

All three of the independent variables, U.S. defense spending, U.S. alloy steel production, and domestic oil demand, are directly related to U.S. molybdenum production. As U.S. defense spending rises, alloy steel production will also rise because alloy steels are used in both weapons and troop support facilities. Molybdenum production closely follows alloy steel production, because speciality steels make up nearly 80 percent of the world demand for molybdenum (Engineering and Mining Journal, March 1981, p. 108 - 109). Alloy steels are also heavily used in energy exploration and development. As the demand for oil grows, exploration and development expenditures increase, therefore, molybdenum's use in exploration equipment will also increase.

2.6 Box-Jenkins Model for Forecasting Molybdenum Production

It was possible to identify the general class of

autoregressive-moving average (ARMA) model for the variable being forecast by studying the patterns in the autocorrelation coefficients and the partial autocorrelation coefficients. Once the general class of ARMA model was identified, different variations on the model were tried. Three criteria were used to determine which model best fit the data: visual inspection of a plot of the residuals, the Box-Pierce Q-statistic (Chi-squared), and the mean squared error (MSE).

A plot of the residuals was examined for each variable to determine if its residuals were randomly distributed. If the residuals were not randomly distributed, if there was still some pattern in them, the model did not adequately describe the variable being forecast.

The Box-Pierce Q-statistic was also used to indicate if there was still a pattern left in the residuals. The Q-statistic determines if several of the autocorrelation coefficients are significantly different from zero. This would indicate that there was still some pattern present in the residuals, and that the model did not adequately describe the data. The equation used to compute the Q-statistic is:

$$Q = n \sum_{k=1}^{m} r_k^2 \qquad (2\text{-}9)$$

where

n = sample size

m = largest time lag included, and

r = autocorrelation coefficient of time lag k

The computed value is compared to the Chi-squared table value. If the computed value is greater than the Chi-squared table value, the autocorrelations are significantly different from zero, indicating that some pattern still exists in the residuals.

The MSE was used as a measure of how close the actual values were to the forecast values; in general, the smaller the MSE is, the better the predictive value of the model. The Box-Jenkins model which best fit the variable being forecast was selected by comparing these 3 criteria. When more than one model had residuals that were randomly distributed and their MSE's were approximately equal, the simpler one, or the one with the fewest estimated parameters was chosen. These criteria were used to select all of the Box-Jenkins models in this thesis.

The variables that were predicted using the Box-Jenkins forecasting technique, and the sources for the variables, are described in Appendix C. The data used to formulate the Box-Jenkins models is listed in Appendix D.

The Box-Jenkins ARMA model which best describes U.S. molybdenum production is an ARMA (1,1) model with seasonality in the moving average portion. It was necessary to add U.S. molybdenum stocks to U.S. molybdenum production to get the data stationary by using one long difference and one short difference. U.S. molybdenum production data would not become stationary using any of the available combinations of short and long differencing in the Sibyl/Runner package. The length of seasonality is 12 months. The equation for the model with the best estimated parameters is shown below:

$$(1-B)(1+.1525B)X_t = (1+.2511B)(1-.7637B^{12})e_t \qquad (2\text{-}10)$$

where the backshift operator B equals:

$$BX_t = X_{t-1} \qquad Be_t = e_{t-1}$$

$$B^{12}e_t = e_{t-12}$$

Mean Squared Error = 39327.6

Chi-Squared (computed) = 18.16 with 24 degrees of freedom

Using backforecasting to check the predictive ability of the Box-Jenkins model for U.S. molybdenum production, yielded the results listed below in Table 2.4:

Table 2.4

Backforecasts for U.S. Molybdenum Production 1980-1981
(in thousands of pounds molybdenum)

Date		Actual Value	Forecast Value	95 Percent Confidence Interval Bounds	
1980	January	2399.0	2280.6	1884.0	2677.3
	February	2296.8	2412.9	2016.3	2809.3
	March	2683.3	2471.7	2075.0	2868.3
	April	2630.6	2652.9	2256.3	3049.5
	May	2504.7	2623.7	2227.0	3020.3
	June	2243.5	2485.3	2088.7	2881.9
	July	2162.7	2109.4	1712.8	2506.1
	August	2362.3	2391.4	1994.7	2788.0
	September	2453.0	2309.3	1912.7	2705.9
	October	2686.2	2438.5	2041.8	2835.1
	November	2793.8	2634.0	2237.3	3030.6
	December	3062.4	2514.9	2118.2	2911.5
1981	January	2842.5	3175.2	2778.6	3571.8
	February	2820.8	2882.5	2485.9	3279.2
	March	3329.7	3029.6	2633.0	3426.2
	April	3294.3	3284.4	2887.8	3681.0
	May	3288.8	3259.0	2862.4	3655.6
	June	3441.7	3200.4	2803.8	3597.0
	July	3678.4	3281.2	2884.6	3677.8
	August	4017.8	3874.8	3478.2	4271.5
	September	3851.0	3988.8	3692.2	4385.5
	October	4251.2	3921.9	3525.3	4318.5
	November	4457.6	4216.2	3819.5	4612.8
	December	4505.7	4301.5	3904.8	4698.1

Backforecasting uses the selected model to forecast the last 24 months of U.S. molybdenum production, allowing the user to compare actual values with predicted values. The forecast values for U.S. molybdenum production for 1980 and 1981 were all close to the actual values. All of the forecast values fell within the 95 percent confidence interval bounds.

2.7 Molybdenum Prospects

Exploration programs that were begun in the late 1970's were very successful in identifying new molybdenum deposits. There are a number of orebodies, like Mt. Emmons, Mt. Tolman, and Quartz Hill, that have been fairly well delineated, and are merely waiting for investment approval to enter the mine development stage. Most of the prospects are still in the exploration stage. Current molybdenum prospects are listed below in Table 2.5. The information available on the prospects is often sketchy, but that is the way mining exploration operates.

TABLE 2.5

MOLYBDENUM PROSPECTS

	Production Begins	Mine Production Capacity (in thousands of pounds of molybdenum per year)	Estimated Cost (in million of dollars)
United States			
AMAX			
Mt. Emmons*	1989	29,762	700
Buckingham	N/A	20,000**	N/A
U.S. Borax			
Quartz Hill*	1987	39,683	870
Getty			
Pina Grove	1988	9,921**	N/A
Casa Grande	N/A	3,307**	N/A
EXXON			
Mt. Hope	N/A	20,000**	350**
Colville			
Mt. Tolman	N/A	20,000	500
U.S. TOTAL		142,673	
Canada			
Placer			
Adanac	N/A	7,937**	N/A
Newmont			
Trout Lake	N/A	20,000**	N/A
CANADA TOTAL		27,937	
Mexico			
Penoles-AMAX			
Opodepe	N/A	9,921**	N/A
MEXICAN TOTAL		9,921	
Chile			
Codelco			
El Abra	N/A	3,858**	N/A
ARCO(Anaconda)			
Los Pelambres	1987	9,921	2,000
EXXON			
Los Broncos	N/A	8,818	3,000
Falconbridge			
Quebrada Blanca	1985	2,205	500
Enami			
Andacollo	N/A	1,543**	N/A
CHILE TOTAL		26,345	

*Denotes a primary molybdenum mine; all others are by-product or co-product mines.

**Value is estimated.

N/A means the information was available.

TABLE 2.5 (continued)

MOLYBDENUM PROSPECTS

	Production Begins	Mine Production Capacity (in thousands of pounds of molybdenum per year)	Estimated Cost (in millions of dollars)
Argentina			
Fluor(St. Joe)			
El Pachon	N/A	2,205	1,300
AGRENTINA TOTAL		2,205	
U.S.S.R.			
Government			
Karatas IV	N/A	13,228	N/A
U.S.S.R. TOTAL		13,228	
Korea			
Hyundai-AMAX			
Sangdong	1991	13,228	814
KOREA TOTAL		13,228	
China			
Government			
Heilungjang	1983	2,205	N/A
CHINA TOTAL		2,205	
Pakistan			
MuHinational			
Saindak	N/A	1,982	250
PAKISTAN TOTAL		1,982	
TOTAL WORLD POTENTIAL CAPACITY		239,724	

*Denotes a primary molybdenum mine; all others are by-product or co-product mines.

**Value is estimated.

N/A means the information was not available.

SOURCE: Sutulov, Intermet Molybdenum Yearbook 1982, p. 333.

CHAPTER 3

3.1 FORECASTING MODELS FOR MOLYBDENUM DEMAND AN INTRODUCTION

This chapter presents the forecasting models that will be used to predict both world and U.S. molybdenum consumption for the next five years. Before presenting the models, both world molybdenum consumption and U.S. molybdenum consumption by end use will be reviewed. Changes that have occurred in U.S. molybdenum consumption during the last ten years will also be examined.

The forecasting models for molybdenum consumption will then be presented. They will be followed by a discussion of potential growth areas for molybdenum consumption; substitutes for molybdenum will also be considered. The last subject that will be examined in this chapter will be the implications of Soviet bloc demand.

3.2 World Molybdenum Consumption

Speciality steels, which include carbon steels, alloy steels, stainless steels, and tool steels, comprise 77 percent of the world's demand for molybdenum. Molybdenum used in metallurgical applications, like superalloys, cast irons, and molybdenum metal, makes up 14 percent of the world

demand. Chemical uses, including pigments and catalysts, consume 9 percent of the world's molybdenum (Engineering and Mining Journal, March 1981, p. 108 - 109). For a more detailed listing of world molybdenum consumption by major industrial categories, the reader is referred back to Table 1.1 in Chapter 1.

The figures that are listed above reflect world-wide consumption averages. The degree of economic development of a country is often reflected by its proportion of speciality steel output to total steel output. This is illustrated by the fact that speciality steels comprise 30 percent of Swedish steel output, while only 5.5 percent of Eastern European steel production is in speciality steels (Sutulov, 1981, p. 39). The U.S. proportion is currently around 14 percent (Metal Statistics, 1981, p. 182). The relationship between economic development, speciality steel production, and molybdenum consumption is illustrated by the following table:

Table 3.1

Geographic Distribution of Current Molybdenum Consumption

Geographic Region	Molybdenum Consumption (thousands of pounds per year)	Percentage of Total Consumption
United States	70,548 - 74,957	32
Western Europe	68,343 - 70,548	30
Eastern Europe	41,888 - 44,092	19
Japan	24,251 - 26,455	11
All Others	15,432 - 19,842	8
TOTAL	220,462 - 235,894	100

SOURCE: Sutulov, Molybdenum Market Study 1981-1990, p. 25.

The more industrialized regions consume more molybdenum because they produce larger amount of speciality steels.

Steel industries have been developing in Latin American nations like Brazil, Argentina, and Mexico. Korea and India are also expanding their steel production capacities. Although steel production in these countries will probably become a significant factor in the future, they currently consume less than 10 percent of the world demand for molybdenum. This percentage is not expected to change radically within the next five years.

3.3 U.S. Molybdenum Consumption

The composition of the U.S. demand for molybdenum is slightly different from that of world demand. Speciality steels comprise 66 percent of the U.S. demand for molybdenum, metallurgical applications comprise 24 percent, and chemical uses comprise 10 percent. For a more detailed listing of U.S. consumption by end use, the reader is referred back to Table 1.2 in Chapter 1. The differences between world demand and U.S. demand can be attributed to the relative abundance of molybdenum in the U.S. The U.S. has sought to use molybdenum in as many different applications as possible, whereas, other countries have primarily used molybdenum for its alloying properties.

Changes that have occurred in U.S. demand over the last decade are shown in the following table:

Table 3.2

U.S. Consumption of Molybdenum by End Use
(in percentage)

End Use	1970	1980
Steel:		
Carbon	6.6	4.8
Stainless and Heat Resisting	12.7	14.8
Alloy:	40.0[1]	
Full alloy	----	36.6
High-strength, low alloy	----	3.2
Tool	5.5	6.1
Cast irons	8.7	5.8
Superalloys	5.5	8.5
Alloys (excludes steels and superalloys)	1.8	2.0
Mill products made from metal powder	3.8	7.9
Chemical and ceramic uses:		
Pigments	2.3	1.2
Catalysts	4.0	5.0
Other	1.9	2.0
Miscellaneous and unspecified	7.2	2.1
TOTAL	100.0	100.0

[1]Full alloy steel and high-strength, low-alloy steel were listed as one category, termed alloy steel, previous to 1972.

SOURCE: Minerals Yearbook, 1970, p. 730 and 1980, p. 577.

Although speciality steels have retained approximately the same percentage of U.S. molybdenum consumption, consumption within the different categories of speciality steels has changed. Molybdenum's use in carbon steels and alloy steels has decreased over the past ten years, while its use in stainless steels and tool steels has increased. Metallurgical applications have increased from 20 percent of the molybdenum demand in 1970 to 24 percent of molybdenum demand in 1980. As was the case with speciality steels, certain categories within metallurgical applications have grown while other have decreased. Molybdenum's use in superalloys and molybdenum metal has grown substantially, its use in other alloys has grown slightly, while its use in cast irons has decreased. Within chemical uses, the demand for molybdenum in catalysts has increased, while the demand for molybdenum in pigments has decreased. It is important to note that end use categories over the past 10 years have become more clearly defined; the percentage of molybdenum listed as miscellaneous or unspecified has diminished.

3.4 Regression Models for Forecasting Molybdenum Consumption

The data used to formulate the world regression equation is listed in Appendix E; the sources for the data are described in detail in Appendix B.

The regression equation which best describes, following the definition presented in section 2.5 of Chapter 2, world molybdenum consumption is:

$$Y = -57.03 + .0137\ (\text{World Copper Production}) + .211\ (\text{World Steel Production}) \qquad (3\text{-}1)$$

t-statistics: $a = -8.70$ $b_1 = 3.01$ $b_2 = 7.18$

$R^2 = 98.5$

$\bar{R}^2 = 98.4$

Durbin-Watson statistic = 1.50

Both independent variables, world steel production and world copper production, are directly related to world molybdenum consumption. Although speciality steels, the largest use for molybdenum, are only a fraction of total steel production, increases or decreases in their production generally follow total raw steel output.

As copper production rises, molybdenum production will also rise because approximately 40 percent of the world's molybdenum production is a by-product from copper mining (Duval, 1981, p. B29).

Backforecasting is one way of checking the predictive ability of regression equations. Backforecasting for world molybdenum consumption involved deleting the last 5 years of data from the data base, then using the regression equation generated by the remaining 19 years of data to forecast the missing 5 values. The results of backforecasting world molybdenum consumption are listed below in Table 3.3.

Table 3.3

Backforecasts for World Molybdenum Consumption 1976-1980 (in millions of pounds molybdenum)

Year	Actual Value	Forecast Value	95 Percent Confidence Interval Bounds
1976	177	182.1	77.9, 286.3
1977	182	182.8	78.6, 278.0
1978	200	194.1	89.9, 298.3
1979	205	202.1	97.9, 306.3
1980	182	194.2	90.0, 298.4

The forecast values for world molybdenum consumption for 1976 through 1980 were all close to the actual values, and fell within the 95 percent confidence interval bounds. The results also indicate that the forecast values followed the actual trends in the market.

The data used to formulate the U.S. regression equations is listed in Appendix F; the sources for the data are described in detail in Appendix A.

The regression equation which best describes, as was defined in section 2.5 of Chapter 2, U.S. molybdenum consumption is:

$$Y = 10410 + 2.80 \text{ (Alloy Steel Production)} \qquad (3\text{-}2)$$

t-statistics: $a = 5.36$ $b_1 = 18.65$

$R^2 = 93.3$

$\bar{R}^2 = 93.0$

Durbin-Watson statistic = 1.12

Only one independent variable, alloy steel production, is used to predict U.S. molybdenum consumption. Alloy steel production is the largest end use for molybdenum in the U.S.; therefore, as alloy steel production rises, molybdenum consumption will also rise.

3.5 Box-Jenkins Model for Forecasting Molybdenum Consumption

The Box-Jenkins autoregressive-moving average (ARMA) model which best describes, based on the definition presented in section 2.6 of Chapter 2, U.S. molybdenum consumption is an ARMA (1,1) model with seasonality in the moving average portion. One short difference and one long difference

were required to get the data stationary; the length of seasonality is 12 months. The equation for the model with the estimated parameters is shown below:

$$(1-B)(1+.2911B)X_t = (1+.5233B)(1-.8741B^{12})e_t \qquad (3-3)$$

where the backshift operator B equals:

$$BX_t = X_{t-1} \qquad Be_t = e_{t-1}$$

$$B^{12}e_t = e_{t-12}$$

Mean Squared Error = 14509.4

Chi-Squared (computed) = 21.98 with 24 degrees of freedom

3.6 Potential Areas for Growth and Substitutability

Both regression models emphasized that molybdenum consumption is highly dependent on speciality steel production. Two of the major reasons for future growth in speciality steels production will be energy exploration and development and increased military expenditures.

Molybdenum in alloy steels increases strength, improves corrosion resistance, and provides the ability to withstand extreme temperatures; these properties make it a valuable additive to steel that will be used in energy exploration and development. Since all of the easily accessible petroleum reserves have been developed, exploration wells

must be drilled deeper, and in harsher environments like Prudhoe Bay and the North Sea. Since the energy crisis in 1973, oil companies have been seeking to develop new domestic oil reserves because foreign sources have proved to be unstable. The combination of these two factors has led to expanded drilling activity. Molybdenum steel is used in drilling bits, drill steel, and support equipment.

Molybdenum steel is also used extensively in pipelines. Although the Canadian government cancelled the Alaska Highway natural gas pipeline in 1981, other pipelines through hostile environments will undoubtedly consume a considerable amount of molybdenum in the future. Alexander Sutulov, in his Molybdenum Market Study 1981-1990 (1981, p. 47), estimates that large diameter welded pipes consume roughly 5.5 million pounds of molybdenum a year.

Exploration and development projects for other energy sources, like coal, also use molybdenum steel. Coal resources have been carefully delineated during the past 10 years, and mine development has continued to grow. Molybdenum steel's strength and wear resistance has made it valuable in mining activity. Mining and milling equipment, like haulage trucks, crushing equipment, and drill rigs,

all use molybdenum alloy steels.

Military outlays provide a promising area for growth in speciality steels production. U.S. Defense Department spending increased 7.3 percent in 1981 and 6.7 percent in 1982 (Statistical Abstract of the United States, Bureau of the Census, 1981, p. 354). This trend promises to continue with the Reagan administration in office. Molybdenum is important to actual weapons development, like airplanes, missiles, and rockets; it is also important to personnel support facilities, such as transport trucks. The goal of developing a four ocean navy will also require a significant amount of speciality steels for new submarines and ships.

Substitution of other metals for molybdenum was never a problem until spot prices hit a record high of over $30 a pound in 1979. Japanese steel manufacturers began replacing molybdenum with vanadium and niobium; Western Europe steel manufacturers used chrome and magnesium (Sutulov, 1981, p. 56). This substitution of other metals was only temporary; as molybdenum prices dropped in 1980, steel manufacturers returned to molybdenum. Molybdenum has traditionally been less expensive and more readily available than its alternatives, tungsten, chromium, niobium, and vanadium. AMAX, through research and

development, has created a relatively stable demand for the metal. The current oversupply of molybdenum, and the abundance of new reserves, make substitution a rather minor problem in the near future.

3.7 Implications of Soviet Demand

Soviet bloc nations have increased their consumption of molybdenum from 22 million pounds in 1970 to 43 million pounds in 1980 (Sutulov, 1981, p. 12). The U.S.S.R. is the only major molybdenum producer in Eastern Europe, and they have not been able to meet the demand for all their satellite countries. Exports from the West to Eastern Europe reached 22 million pounds a year in 1979 and 1980 (Sutulov, 1981, p. 13). A significant portion of the U.S.S.R.'s 1979 demand can be attributed to their rearmament program due to the invasion of Afganistan.

One of the major problems with Soviet bloc demand is that it is highly unpredictable. Long-term contracts between Eastern Europe and the western producing nations do not exist; most of their purchases are made through western European merchants. A large part of the molybdenite concentrate sold to Belgium is converted to molybdic oxide and sold to Eastern Europe (T.D. Kaufmann, oral

communication, March 1982). The advantage to centrally planned economies is that they can demand discounts on large molybdenum purchases, especially when the market is soft. An example of this would be Duval's sale of 1,900 tons of molybdic oxide to the Soviet Union in March of 1982 at $2 below the overseas list price (Metals Week, March 29, 1982, p. 6).

Sutulov, in his Molybdenum Market Study 1981 - 1990 (1981, p. 25 and p. 70), estimates that the U.S.S.R. is only 50 to 60 percent self-sufficient in molybdenum production. This means that Soviet bloc nations will be forced to buy western molybdenum, but the timing and amounts of their purchases will be difficult to predict.

CHAPTER 4

4.1 FORECASTING MODELS FOR MOLYBDENUM PRICE AN INTRODUCTION

Chapter 4 presents the forecasting models that will be used to predict molybdic oxide price for the next five years. Before presenting the models, the recent history of molybdenum prices will be reviewed. Reasons behind current price fluctuations will also be explored.

The forecasting models for molybdic oxide price will then be presented. After the models have been presented, the future of the current pricing system will be examined.

4.2 Forecasting U.S. Producer Prices

Domestic producer price for technical grade molybdic oxide is the price that will be forecast in this thesis. Technical grade molybdic oxide is the most widely traded form of molybdenum; it is sold for direct use in steel-making and for conversion to chemical uses. Nearly 97 percent of all molybdenite concentrate is converted to technical grade molybdic oxide (Sutulov, Volume III, 1980, p. 190). Although dealer prices, termed free market prices, are often used to indicate the state of the

molybdenum market, 85 percent of all molybdenum supplies are sold by producers (W.A. Goldman, oral communication, May, 1982).

The U.S. is the world's largest producer of molybdenum; it is currently responsible for approximately 67 percent of world production (Sutulov, 1982, p. 7). AMAX itself produces 45 percent of the world's molybdenum. Climax concentrate has traditionally been the basis for molybdenum product prices; hence, the domestic producer price for technical grade molybdic oxide will be forecast.

During the past year there have been problems with the multi-tiered pricing system for molybdenum products; these problems will be examined in section 4.6. The recent history of molybdenum prices will be outlined in the next section.

4.3 Recent History of Molybdic Oxide Prices

Domestic and export prices for molybdenum products were established in 1979 by the U.S. and Canadian producers to protect domestic consumers. The drop in demand for molybdenum during 1981 and 1982, however, has seriously undermined this pricing system.

Climax dropped its domestic molybdic oxide price for the first time in 20 years from $9.70 to $9.35 in March of 1981 (Metals Week, March 9, 1981, p. 2). It then lowered the price again in August of 1981 from $9.35 to $8.50 (Metals Week, August 3, 1981, p. 3). Climax's molybdic oxide is still listed at $8.50 a pound; however, the price is nominal, meaning that no appreciable amount is being sold at that price. Sutulov, in his Molybdenum Yearbook 1982, (1982, p. 10), states that by the fourth quarter of 1981, Climax was unofficially selling its oxide at $6.85 per pound to be competitive with other producers.

Free market prices, or dealer prices, have fluctuated more than producer prices. Although dealers control only 15 percent of the market, their prices are often used as indicators of the current market situation. From a record high of over $30 a pound in 1979, free market prices dropped to $14 a pound near the beginning of 1980. By July of 1980, they had declined from $14 to $8 a pound. Dealer prices remained around the $8 level for a year, then in July of 1981 began to drop rapidly. By December of 1981 they had reached a new low of around $3.30 a pound (Metals Week, March 15, 1982, p. 3). Free market prices briefly rose above $5 a pound in late March of 1982, but

have since dropped 14 percent to their current level of between $4.40 - 4.80 a pound (Metals Week, May 31, 1982, p. 1).

There has been a great deal of speculation as to what caused the current oversupply of molybdenum, and its precipitous price drop in 1981-82. Most of the investment decisions to build new molybdenum mines, or to expand existing facilities, were made in 1979, the year when molybdenum prices reached record highs. Two of the most important reasons behind the record prices in 1979 were the Canadian molybdenum strike, and large purchases of molybdenum by the U.S.S.R.

Canada, the world's second largest producer of molybdenum, experienced a 10-month strike during 1979. The strike caused a one-third reduction in Canada's yearly production. During the same time period, the Soviets were purchasing large amount of molybdenum for their rearmament program due to their invasion of Afganistan. These two reasons combined drove molybdenum prices to record highs, which in turn caused molybdenum producers to lose control over their pricing system (Sutulov, 1982, p. 9).

Investing in exploration and development of new molybdenum mines looked quite attractive with free market prices over $30 a pound. Many mining and oil companies did invest large sums of money in molybdenum prospects; however, the Canadian strike ended, and the U.S.S.R. substantially decreased its purchases. The recent decline in Soviet purchases of western molybdenum is partially due to their own economic difficulties, and partially due to their new domestic sources of molybdenum. These problems were enhanced by the beginning of the recession in 1980; western demand for molybdenum decreased as the steel market began to soften (Sutulov, 1982, p. 10).

4.4 Regression Models

Two regression models were created for domestic technical grade molybdic oxide price, one for nominal price and one for real price. Real price was obtained by deflating nominal prices by the Producer Price Index (PPI) for the appropriate time period.

Before presenting the two regression models, it is important to note the scaling factors involved with the two models. The regression coefficients may seem inordinately

small, until the difference in scaling factors is considered. All three prices used in the models, nominal price for molybdenum and nickel, and real price for molybdenum, are in dollars. Molybdenum price is being regressed against aerospace sales and new tool orders in millions of dollars, and against molybdenum consumption in thousands of pounds contained molybdenum. The problem is enhanced in the case of real price where nominal price has been divided by the PPI, making the dependent variable even smaller. Although the regression coefficients may appear to be small, all of the t-test values indicate that the coefficients of the independent variables are statistically significant at the 95 percent confidence interval. F-tests for the two equations also indicate that the equations as a whole are significant; therefore, it is simply a matter of the difference in scaling.

The data used to formulate the U.S. regression equations are listed in Appendix F; the sources for the data are described in detail in Appendix A.

The regression equation which best describes, following the definition presented in section 2.5 of Chapter 2, domestic nominal price for technical grade oxide is:

$$Y = 1.94 + 1.0 \times 10^{-4} \text{ (Aerospace Sales)} + .591 \text{ (Nickel Producer Price)} - 7.78 \times 10^{-5} \text{ (Molybdenum Consumption)} + 8.63 \times 10^{-4} \text{ (Metal Cutting Tools)} \quad (4\text{-}1)$$

t-statistics: $a = 5.98$ $b_1 = 7.99$

$b_2 = 2.56$ $b_3 = -8.99$

$b_4 = 7.68$

$R^2 = 98.3$

$\bar{R}^2 = 97.9$

Durbin-Watson statistic = 2.08

Three of the independent variables, aerospace vehicle sales, new orders for metal cutting type machine tools, and nominal nickel producer price, are directly related to nominal molybdenum price. The last variable, molybdenum consumption, is inversely related to nominal molybdenum price. As was mentioned in the previous chapter, molybdenum's use in both tool steels and superalloys has grown substantially in the last 10 years; therefore, the direct relationship between the increasing use for molybdenum in these products and nominal price for molybdenum is to be expected. Aerospace sales are primarily dependent on defense spending, which in turn is dependent on the political policies of the current administration. Tool

orders vary with the general economy; in times of expansion they do exceptionally well, whereas in times of recession they do poorly. They are highly dependent on the level of capital expenditure.

Nickel is also used as an important alloying agent in steels. Like molybdenum, it closely follows the steel production cycle. When the demand for steel is high, nickel price will rise in response to increased consumption of the metal. The price movements in the nickel and molybdenum markets should be parallel, as is indicated in equation (4-1).

Nominal price is inversely related to molybdenum consumption. As price rises, molybdenum consumption will decrease; this was observed in both Japan and western Europe during 1979. Other metals were substituted for molybdenum when the large price increase occured. Very little substitution takes place with a moderate price increase; this is substantiated by the size of the regression coefficient for molybdenum consumption. Even allowing for the difference in scaling factors between price and consumption, the regression coefficient is small. Sutulov agrees with this in his Molybdenum Market Study 1981 - 1990 (1981, p. 57) by stating,

"that in short run molybdenum has, as most base metals, low elasticity in demand, i.e. price hiking does not produce a quick reaction in demand in the sense that a certain increase in prices reduces by the same percent or more its consumption." He attributes this low elasticity of demand to the fact that molybdenum is used in relatively small quantities in alloy steel; therefore, molybdenum price increases do not substantially affect the price of finished goods (Sutulov, 1981, p. 57).

The regression equation that best describes, as was defined in section 2.5 of Chapter 2, domestic real price for technical grade oxide is:

$$Z = .0189 - 2.378 \times 10^{-7} \text{ (Molybdenum Consumption)} + 2.74 \times 10^{-7} \text{ (Aerospace Sales)} + 2.38 \times 10^{-6} \text{ (Metal Cutting Tools)} \qquad (4\text{-}2)$$

t-statistics: $a = 11.23$ $b_1 = -5.22$ $b_2 = 8.91$ $b_3 = 4.38$

$R^2 = 91.4$

$\bar{R}^2 = 90.3$

Durbin-Watson statistic = 1.07

Two of the independent variables, aerospace vehicle sales and new orders for metal cutting type machine tools, are directly related to real price. The third variable,

molybdenum consumption, is inversely related to real price. This equation is quite similar to equation (4-1), as should be expected. Although the independent variables have different coefficients in equations (4-1) and (4-2), the reasons for their inclusion in equation (4-2) have not changed.

The regression coefficients are smaller because the dependent variable has decreased due to its division by the PPI. Nominal price for nickel is no longer included in the real price equation. Nominal prices have grown rapidly within the last ten years, while real prices have remained relatively constant; therefore, the nominal price for nickel is not as good a predictor for real molybdenum price, as it was for nominal molybdenum price.

4.5 Box-Jenkins Model

The Box-Jenkins autoregressive-moving average (ARMA) model which best describes, as was defined in section 2.6 of Chapter 2, the nominal price, X_t, for molybdic oxide is an ARMA (1,1) model with seasonality in the moving average portion. One short difference and one long difference were required to get the data stationary;

the length of seasonality is 12 months. The equation for the model with the estimated parameters is shown below:

$$(1-B)(1+.7251B)X_t = (1+.7428B)(1-.8812B^{12})e_t \qquad (4-3)$$

where the backshift operator B equals:

$$BX_t = X_{t-1} \qquad Be_t = e_{t-1}$$

$$B^{12}e_t = e_{t-12}$$

Mean Squared Error = .0949

Chi-Squared (computed) = 32.7 with 24 degrees of freedom

The Box-Jenkins autoregressive-moving average (ARMA) model which best describes, based on the definition in section 2.6 of Chapter 2, the real price, Z_t, for molybdic oxide is an ARMA (1,1) model with seasonality in the auto-regressive portion. One short difference and two long differences were required to get the data stationary; the length of seasonality is 12 months. The equation for the model with the estimated parameters is shown below:

$$(1-B)(1+.3371B)(1+1.7548B^{12}-.8774B^{24})Z_t = (1+.6378B)e_t \qquad (4-4)$$

where the backshift operator B equals:

$$BZ_t = Z_{t-1} \qquad Be_t = e_{t-1}$$

$$B^{12}Z_t = Z_{t-12}$$

$$B^{24}Z_t = Z_{t-24}$$

Mean Squared Error = 2.4×10^{-5}

Chi-Squared (computed) = 18.02 with 20 degrees of freedom

In both cases the mean squared error (MSE) looks exceptionally small, but that is due to the size of the numbers being predicted. Both nominal price and real price are listed in dollars; squaring the error between real and predicted values further diminishes the MSE.

4.6 Predicted Changes in the Pricing System

The multi-tiered pricing system that was established in 1979 to protect North American consumers from changes in the world market seems to be breaking down due to the current oversupply of molybdenum. As was mentioned in the previous chapter, Duval reportedly sold 1,900 tons of molybdic oxide to the U.S.S.R. at $2 below the overseas list price (Metals Week, March 31, 1982, p. 6). Anaconda's tender of 600,000 pounds of molybdenite concentrates from Butte and Anamax further softened the molybdenum market in late May (Metals Week, May 17, 1982, p. 6). Bids for Anaconda's concentrates were so low that they decreased the Metals Week dealer price range from $4.80 to $5.20 down to the $4.70 to $5.05 per pound. Dealer prices for

concentrate continued to drop; the Metals Week (May 31, 1982, p. 5) quote for the week ending May 28, 1982 was from $3.75 to $4.20 a pound.

Europe is currently buying all of its molybdenum from dealers. U.S. consumers are purchasing 20 percent of their molybdenum on the free market, while Japan is buying 30 percent on the free market (Duval, 1981, p. B29). Domestic and export producer list prices are nearly twice the free market price. Multi-tiered producer pricing for molybdenum works well only if there is a large demand for the product. With the current oversupply of molybdenum, companies are more concerned with protecting their own interests than with adhering to the pricing system.

CHAPTER 5

5.1 FORECASTS FOR MOLYBDENUM PRODUCTION, CONSUMPTION, AND PRICE-- AN INTRODUCTION

Forecasts for molybdenum production, consumption, and price for the years 1982 through 1987 are presented in this chapter. Before presenting the multiple regression and Box-Jenkins forecasts, growth rates for molybdenum production, consumption, and price for the last 20 years will be examined. Assumptions made in forecasting will be listed along with the forecast values. The outlook for the molybdenum market in general will be presented in the last section of this chapter.

The purpose of this thesis is to provide a simplified way of looking at the molybdenum market. Large econometric models offer the advantage of being able to study how one segment of the economy, like the mining industry, relates to the entire economy. The problem with large econometric models is that they are so complex that it becomes difficult to isolate the effect of changing a few of the variables. Chase Econometrics in January of 1981,was still predicting that molybdenum demand would keep pace with increasing

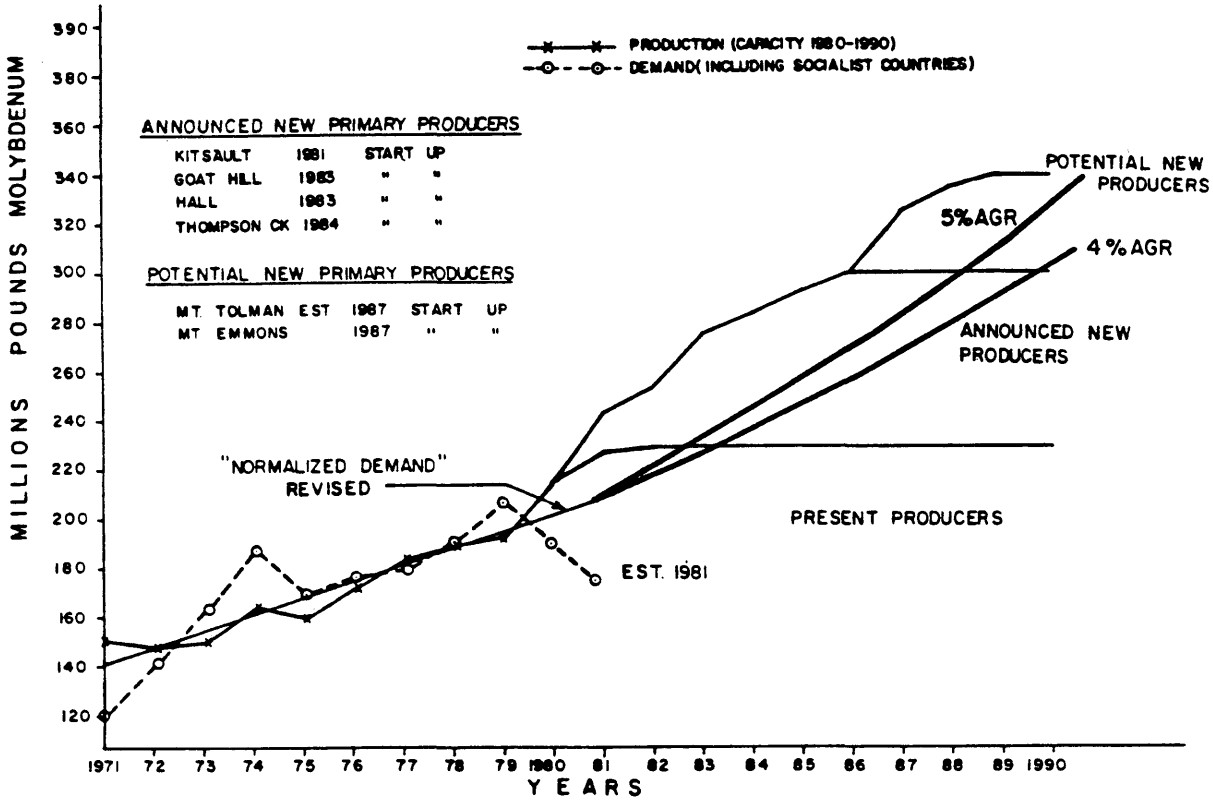
mine capacity throughout the 1980's. They stated that, "Although some excess capacity (is projected for) the 1980-84 period, we are not overly concerned about its effect on the supply-demand balance for several reasons." (Metals Week, January 16, 1981, p. 6). The primary reason for their not begin concerned was that AMAX would still have enough influence to prevent any serious oversupply problems. This view seems to discount the importance of both South American producers, who need the income for their balance of trade, and by-product producers, who need the income to supplement low copper prices.

5.2 Average Annual Growth Rates for Molybdenum Production, Consumption, and Price

The following graph, Figure 5.1, indicates how Placer Development, the largest Canadian producer of molybdenum, viewed the market in November of 1981. J.A. Ganshorn, sales manager for Placer's molybdenum products, felt that the market was no longer expanding at a 7 to 8 percent annual growth rate it exhibited in the previous 15 years, and is currently expanding at only a 4 percent annual growth rate (The Northern Miner, November 26, 1981, p. B28). It is important to note that in Figure 5.1 the "normalized demand" curve is linear.

FIGURE 5.1

FREE WORLD MOLYBDENUM
SUPPLY-DEMAND BALANCE



SOURCE: The Northern Miner, November 26, 1981, p. B28.

through 1981, then switches to a higher order trend to fit the 4 and 5 percent annual growth lines.

Average annual growth rates were calculated for the data used in this thesis; the data is described in detail in Appendices A through C. Table 5.1 lists the average annual growth rates for molybdenum production, consumption, and price. Since different data sets were used, it is

TABLE 5.1

Average Annual Growth Rates for Molybdenum Production, Consumption, and Price (in percent)

	1961-1970	1971-1980
Production		
U.S.	4.7	2.9
World	6.2	2.8
Consumption		
U.S.	3.4	1.6
World	6.3	2.1
Price[1]		
Nominal	2.6	14.0
Real[2]	1.2	6.0

[1]The average annual growth rate listed is for domestic technical grade molybdic oxide.

[2]Real price was obtained by dividing nominal price by the Producer Price Index (PPI).

not surprising that the growth rates calculated in this thesis, and those calculated by Placer, are not equal. Growth rates also depend on the time period selected for their calculation.

From studying Table 5.1, it becomes apparent the growth decade for molybdenum was the 1960's. World production grew at an average of 6.2 percent a year, while U.S. production grew at almost 5 percent a year. World consumption increased at an average of 6.3 percent, slightly

above world production. U.S. consumption grew slower than U.S. production at 3.4 percent a year. Prices did not keep up with either the production or consumption growth rates during the 1960's. Nominal price grew at 2.6 percent a year, while real price grew at only 1.2 percent a year.

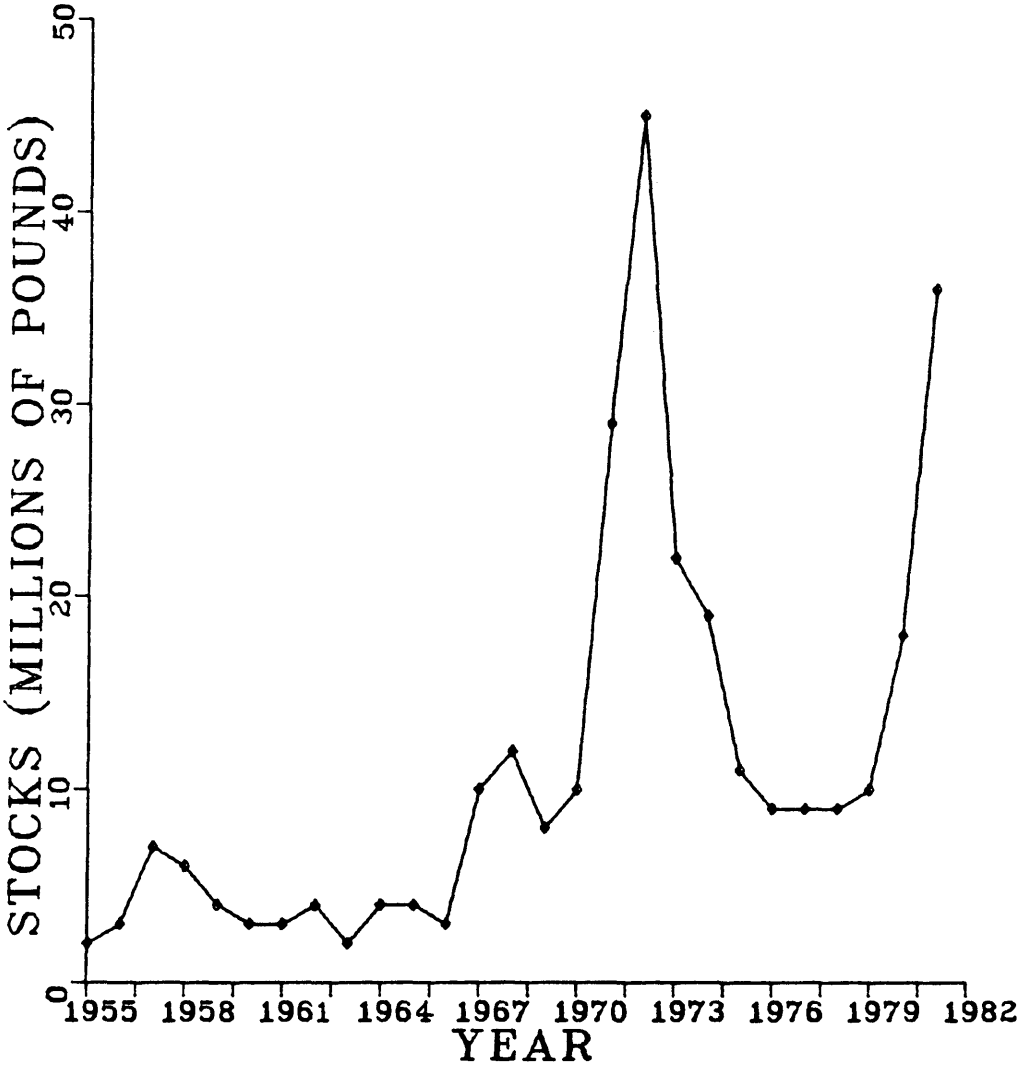
The situation reversed itself in the 1970's; price grew much faster than either production or consumption. Nominal price grew at an average of 14 percent a year; real price grew at an average of 6 percent a year. Both world and U.S. production increased by an average of 3 percent a year. Consumption grew the slowest, with world consumption averaging a 2.1 percent increase, and U.S. consumption averaging a 1.6 percent increase. Reasons behind the differences in growth rates will be examined in the following sections.

5.3 Forecasts for Molybdenum Production

With the current oversupply of molybdenum, U.S. producer stocks have risen sharply in the last two years, as shown in Figure 5.2. Stocks have been higher in the past; in 1972, U.S. producer stocks reached 45 million pounds out of 112 million pounds of yearly production.

FIGURE 5.2

U.S. MOLYBDENUM STOCKS



U.S. producer stocks are currently listed at nearly 40 million pounds out of a yearly production of almost 140 million

pounds (Mineral Industry Survey for Molybdenum, February 1982, p. 1).

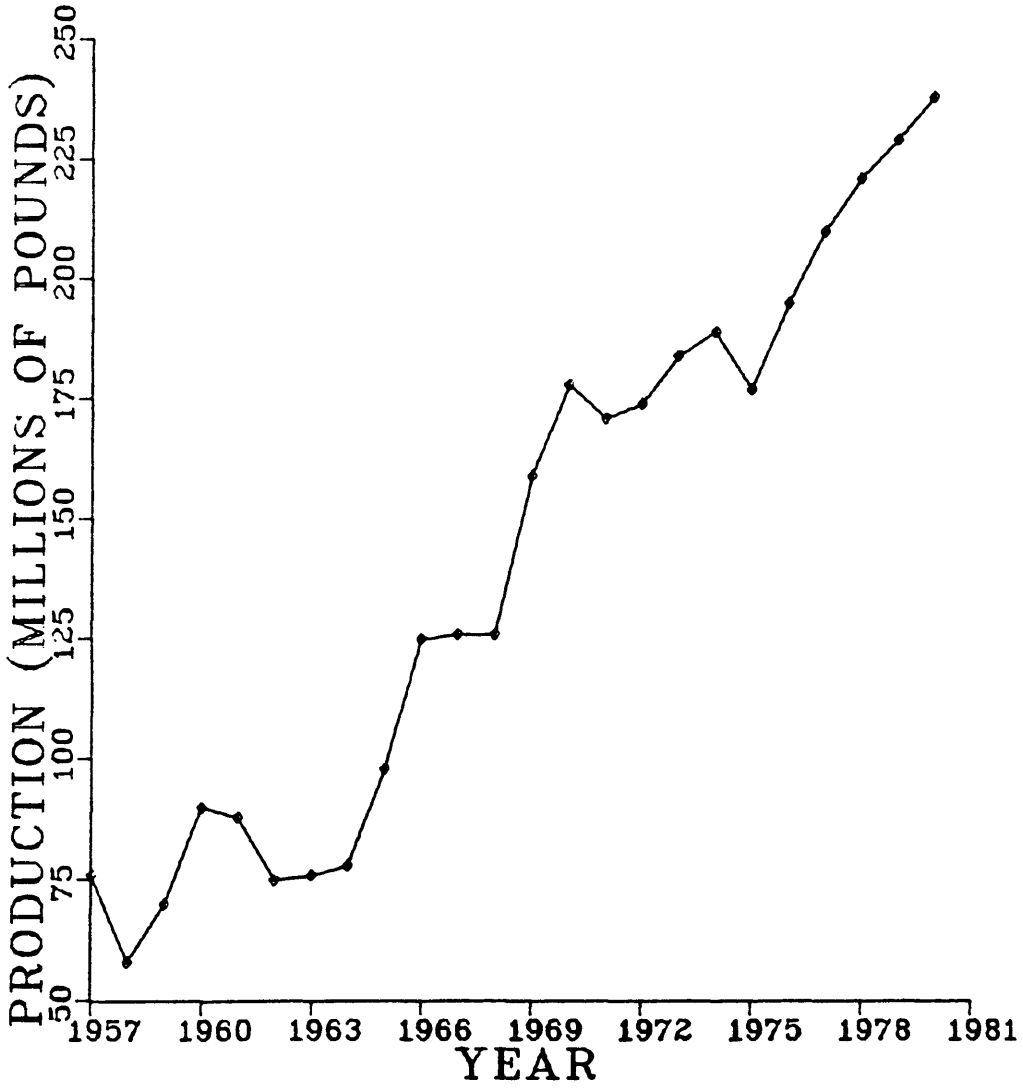
Although producer stocks are quite large, consumers do not have any significant amount of molybdenum stockpiled. With high interest rates, consumers cannot afford to have large inventories waiting to be used. Free market molybdenum prices dropped so rapidly in 1981-82 that purchasers waited until the last possible moment to buy molybdenum, hoping that the price would continue to fall.

World production, as shown in Figure 5.3, has not dropped as rapidly as North American production. South American producers are hesitant to cut back; both Chile and Peru rely heavily on their mineral exports for their balance of trade. The Chilean Copper Commission has been quoted as saying that large production cutbacks are not in the interest of the country, and are "highly improbable" (Metals Week, March 22, 1982, p. 1). Although there have been no mass firings at either El Tiente or Chuquicamata, labor force reductions through early retirement and attrition were undertaken in April (Metals Week, April 5, 1982, p. 8).

Workers at Southern Peru Copper Corporation's Cuajone mine threatened to strike in mid-March, but production has continued (Metals Week, March 22, 1982, p. 1). Peru's

FIGURE 5.3

WORLD MOLYBDENUM PRODUCTION



Labor Minister, Alfonso Grados, is convinced that a major strike will not occur in 1982, even though labor unrest continues (Metals Week, April 12, 1982, p. 1). A meeting of the major copper producing nations is scheduled for July 12 - 14, 1982 in an attempt to formulate a policy to help stabilize copper prices (Metals Week, June 7, 1982, p. 1). Chile is not expected to support any production cutbacks because it is the lowest cost producer of copper, and wishes to take advantage of the situation.

As was stated in section 5.1, world production grew at an average annual rate of 6.2 percent in the 1960's, while U.S. production grew at an average of 4.7 percent. During the 1960's, the U.S. lost nearly 14 percent of the world molybdenum market due to the influx of Canadian and Chilean producers (Sutulov, 1981, p. 75). In the 1970's, both world and U.S. production grew at nearly 3 percent; therefore, the U.S. still controls 63 percent of the world market (Minerals Yearbook, 1980, p. 583).

Growth rates for the independent variables used in the multiple regression equations for molybdenum production are listed in Table 5.2. Average annual growth rates will be compared with what is currently happening in the economy, then estimated growth rates for the variables

will be selected. All assumptions made in forecasting the independent variables will be explained; growth rates assumed for the independent variables will be listed with the forecasts. This allows the reader to apply his own judgment to the forecasts, and to change them if he so desires. The multiple regression forecasts will then be compared to the values obtained from the Box-Jenkins forecasting model. This procedure will apply for all the forecasts for molybdenum production, consumption, and price.

TABLE 5.2

Average Annual Growth Rates for World Steel Production, U.S. Alloy Steel Production, U.S. Defense Spending, U.S. Domestic Oil Demand, and Copper Producer Price

	1961-1970	1971-1980
World Steel Production	5.2	2.3
U.S. Alloy Steel Production	5.1	1.7
U.S. Defense Spending	5.1	4.8
U.S. Domestic Oil Demand	3.9	1.4
Copper Producer Price[1]	5.5	4.9

[1]Copper producer price is the annual average price for electrolytic copper wirebar.

The multiple regression equation for world molybdenum production uses world steel production and copper producer price to forecast future production levels. The regression equation is:

$$Y = -34856 + 901.3 \text{ (Copper Producer Price)} + 226.7 \text{ (World Steel Production)} \quad (2\text{-}7)$$

World steel production declined by nearly 4 percent in 1980, and has continued to decline since that time. Leading economic indicators have begun to indicate the recession has bottomed, and that the economy is beginning to recover (Rocky Mountain News, July 1, 1982, p. 3). Assuming that both the U.S. and the world economy begin to improve, the outlook for steel is favorable. Copper producer prices declined by nearly 17 percent, and have continued to decline. The producer price for cathodes is currently between 68 and 70 cents (Metals Week, June 14, 1982, p. 7). Production cutbacks have been quite severe due to the exceptionally low price. With all of the mine closings that were listed in Chapter 2, copper prices are not expected to remain that low for very long. The values forecast for world molybdenum production are found in Table 5.3:

TABLE 5.3

Multiple Regression Forecasts for World Molybdenum Production

	Average Annual Growth Rate (percent)	1982	1983	1984	1985	1986	1987
World Steel Production (millions of tons)	2.0	770	785	801	817	833	850
Copper Producer Price (dollars)	5.0	.75	.79	.83	.87	.91	.96
World Molybdenum Production Forecast (millions of pounds)		207	214	221	229	236	244
95 Percent Confidence Interval Bounds (millions of pounds)		80,334	87,341	94,348	102,356	109,363	117,371

The annual average growth rates used will tend to smooth out fluctuations in the forecast values. The regression equations formulated in this thesis make it relatively simple for the user to select his own values for the independent variables; this allows him to make forecasts based on his own assumptions, and to constantly update them as changes occur.

U.S. molybdenum production, shown in Figure 5.4, is directly related to U.S. defense spending, U.S. alloy steel production, and domestic oil demand, as shown by equation (2-8).

$$Y = -7955 + 536.5\ (\text{U.S. Defense Spending}) + 206.9\ (\text{U.S. Alloy Steel Production}) + 7.46\ (\text{Domestic Oil Demand}) \qquad (2\text{-}8)$$

Although the annual average growth rate for U.S. defense spending was around 5 percent in the 1970's, in 1981 and 1982 the defense budget increased 7.3 percent and 6.7 percent respectively (Statistical Abstract of the United States, Bureau of the Census, 1982, p. 354). With President Reagan in office, defense spending is expected to continue growing at 7 percent annually. U.S. alloy steel production appears to have reached the bottom of its 5-year cycle in 1980, as is illustrated by Figure 5.5.

FIGURE 5.4

U.S. MOLYBDENUM PRODUCTION

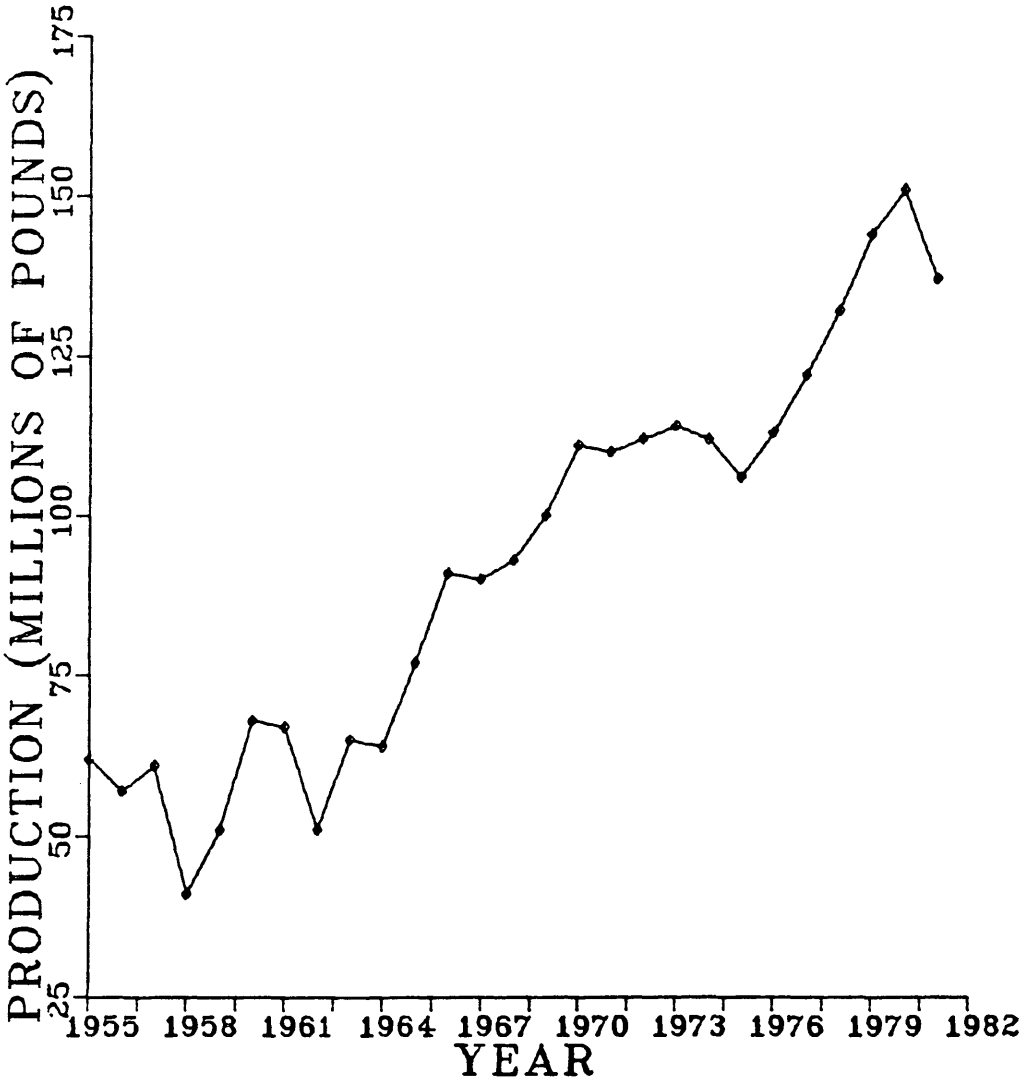
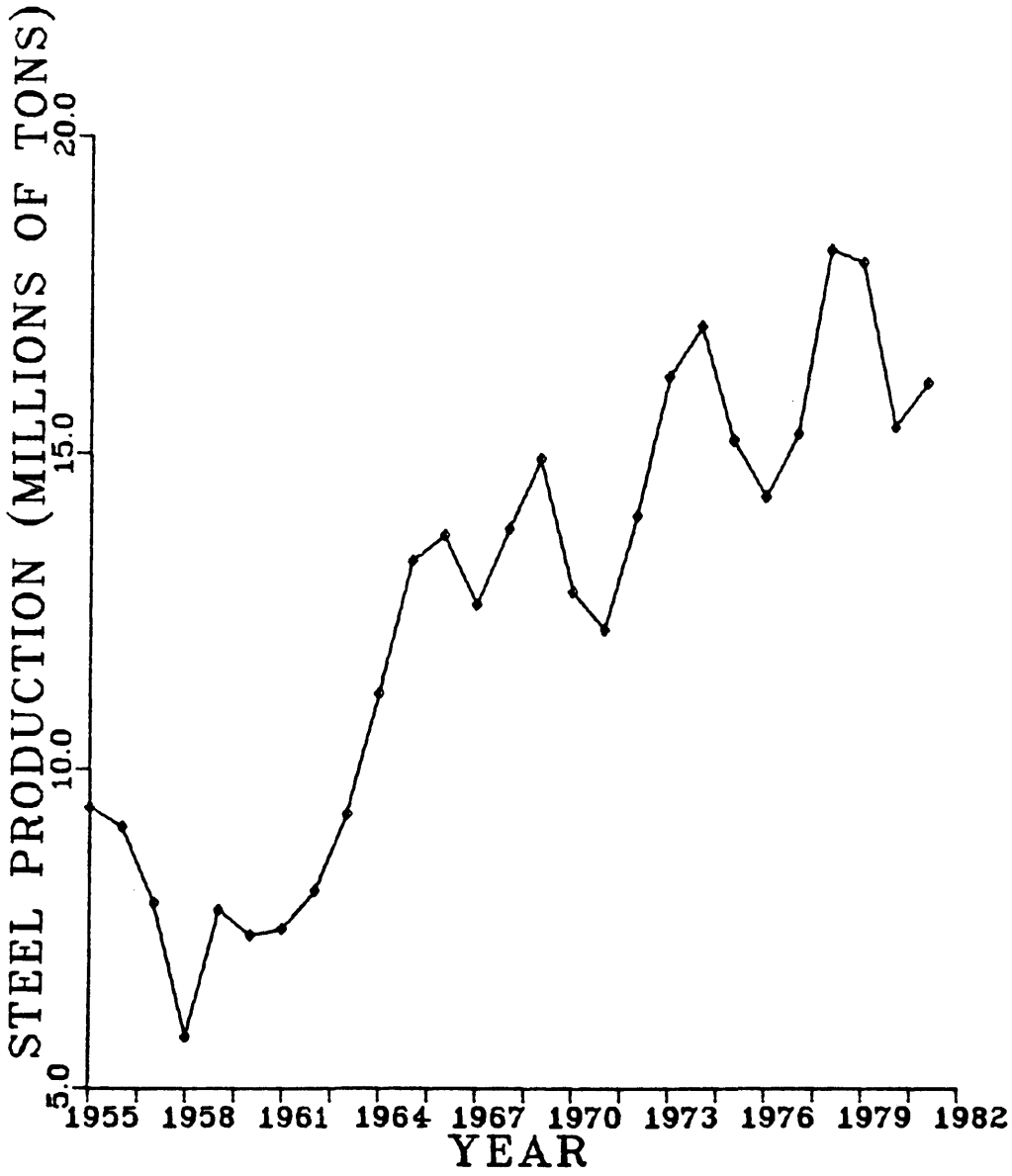


FIGURE 5.5

U.S. ALLOY STEEL PRODUCTION



Alloy steel production rose 3.8 percent in 1981, and is expected to continue to rise. Domestic oil demand decreased by 6.4 percent in 1981. Oil demand varies directly with the state of the economy. Assuming that the recession has bottomed out, oil demand is expected to increase as the economy improves. Based on these assumptions, the following forecasts, listed in Table 5.4 were made for U.S. molybdenum production.

TABLE 5.4

Multiple Regression Forecasts for U.S. Molybdenum Production

	Average Annual Growth Rate (percent)	1982	1983	1984	1985	1986	1987
U.S. Defense Spending (in billions of dollars)	7.0	150	160	171	183	196	210
U.S. Alloy Steel Production (thousands of tons)	2.0	16,400	16,700	17,100	17,400	17,700	18,100
Domestic Oil Demand (millions of barrels)	1.5	5,900	6,000	6,100	6,200	6,300	6,400
U.S. Molybdenum Production Forecast (millions of pounds)		150.5	157.2	164.7	172.5	180.8	189.9
95 Percent Confidence Interval Bounds (millions of pounds)		81.7, 219.3	88.4, 226.0	95.9, 233.5	103.7, 241.3	112.0, 249.6	121.1, 258.7

Using the Box-Jenkins model that was selected for U.S. molybdenum production, as shown in equation (2-10) below, the following 24 monthly forecasts were made:

$$(1-B)(1+.1525B)X_t = (1+.2511B)(1-.7637B^{12})e_t \qquad (2\text{-}10)$$

TABLE 5.5

Box-Jenkins Forecasts for U.S. Molybdenum Production

		Forecast Value (thousands of pounds)	95 Percent Confidence Interval Bounds (thousands of pounds)	
1982	January	45,626	41,660,	49,592
	February	45,573	41,587,	49,558
	March	48,401	44,414,	52,387
	April	48,190	44,203,	52,176
	May	47,860	43,873,	51,846
	June	47,580	43,593,	51,567
	July	47,087	43,100,	51,074
	August	49,645	45,658,	53,632
	September	49,073	45,086,	53,060
	October	50,446	46,459,	54,433
	November	50,094	46,956,	54,930
	December	49,973	45,990,	53,963
1983	January	50,671	46,576,	54,767
	February	50,686	46,490,	54,683
	March	53,422	49,326,	57,519
	April	53,209	49,112,	57,306
	May	52,880	48,783,	56,976
	June	52,600	48,503,	56,697
	July	52,107	48,010,	56,204
	August	54,665	50,568,	58,762
	September	54,093	49,996,	58,190
	October	55,466	51,369,	59,562
	November	55,963	51,866,	60,059
	December	54,996	50,900,	59,093

Totaling the 12 monthly forecasts to obtain a yearly figure makes it possible to compare multiple regression and Box-Jenkins forecasts. It is important to remember that U.S. molybdenum production and stocks were added together to achieve a stationary time-series. Before adding the 12 monthly forecasts, it is necessary to subtract off the stock values. During 1982, molybdenum stocks have been around 37 million pounds. Although leading economic indicators have begun to indicate that the recession is ending, the recovery is expected to be slow. Molybdenum stocks will probably remain near 40 million pounds in 1983, as the steel industry slowly recovers. The Box-Jenkins forecast value for 1982 is 148 million pounds, and the forecast value for 1983 is 161 million pounds. These values are close to ones obtained from multiple regression equations, which are 150.5 million pounds and 157.2 million pounds as shown in Table 5.4.

5.4 Forecasts for Molybdenum Consumption

World molybdenum consumption increased at an average annual growth rate of 2.1 percent during the 1970's. World molybdenum consumption is directly related to

world steel production, as is shown by Figures 5.6 and 5.7. U.S. molybdenum grew at an average rate of 1.6 percent a year in the 1970's. U.S. molybdenum consumption, shown in Figure 5.8, closely follows the patterns that were observed in U.S. alloy steel production, Figure 5.5.

Growth in molybdenum consumption during the last ten years has not kept up with the growth in either production, or production capacity. This does not imply that molybdenum consumption will not increase substantially in the 1980's. As was discussed in Chapter 3, two areas look especially promising for molybdenum: energy development and rearmament programs. Energy exploration has moved to more hostile environments, making stronger and more corrosion resistant steels necessary. Molybdenum as an additive strengthens steel and improves corrosion resistance, making it a valuable alloy in both drill steel and pipelines. Rearmament programs, and the hostilities in the Middle East and Argentina, increase the demand for molybdenum. Molybdenum is used in aircraft and missiles, along with troop support facilities.

The average annual growth rates for the independent variables used to forecast molybdenum consumption are listed below in Table 5.6.

FIGURE 5.6

WORLD MOLYBDENUM CONSUMPTION

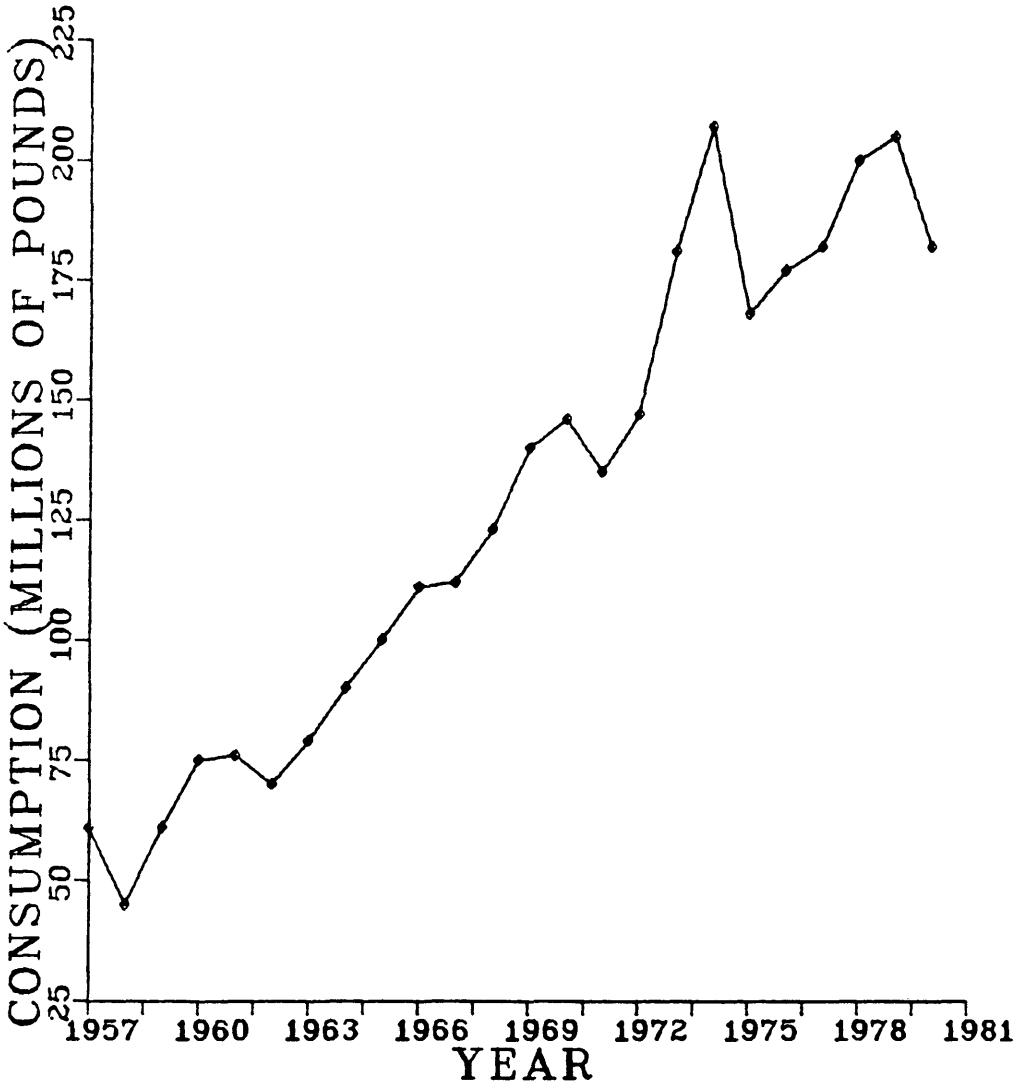


FIGURE 5.7

WORLD STEEL PRODUCTION

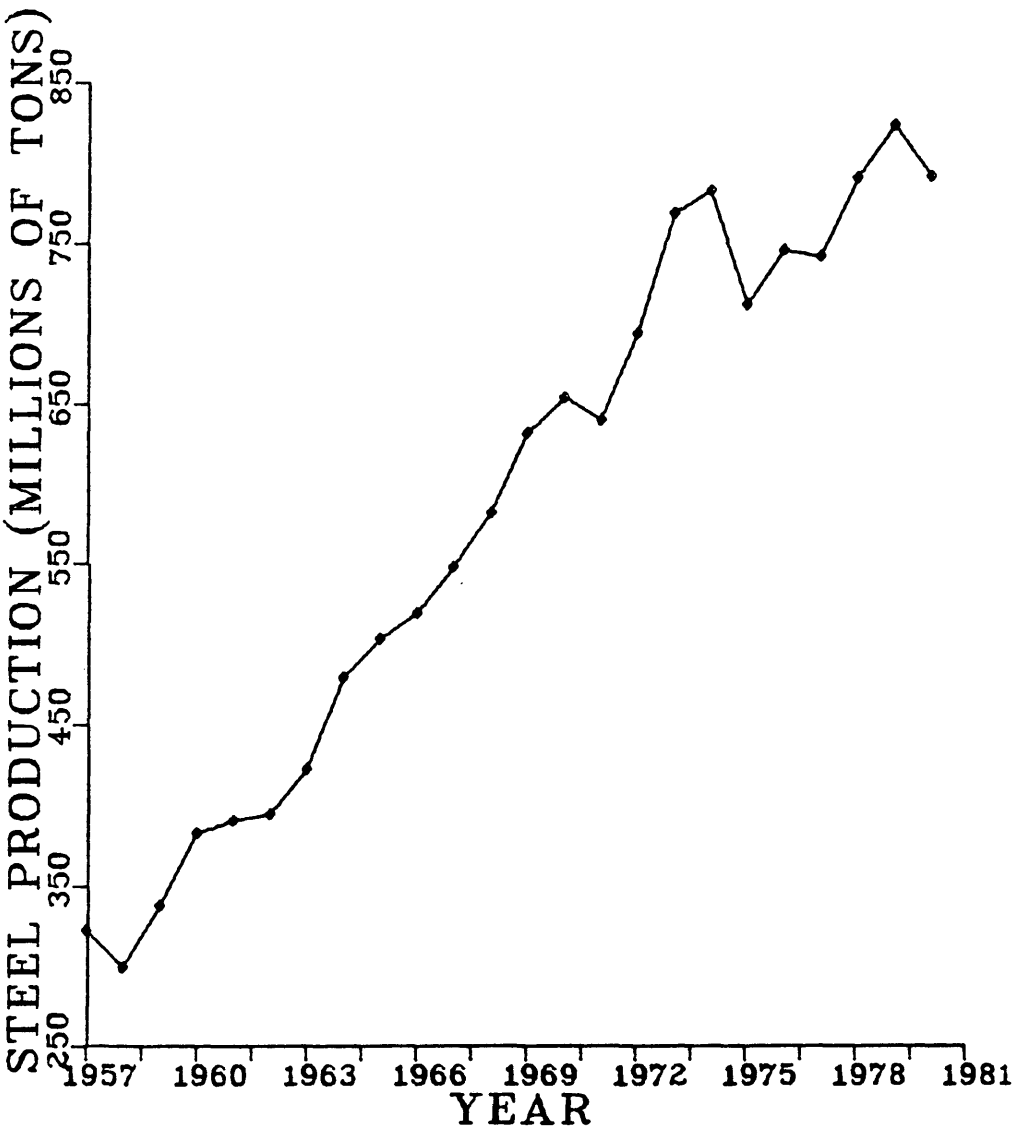


FIGURE 5.8

U.S. MOLYBDENUM CONSUMPTION

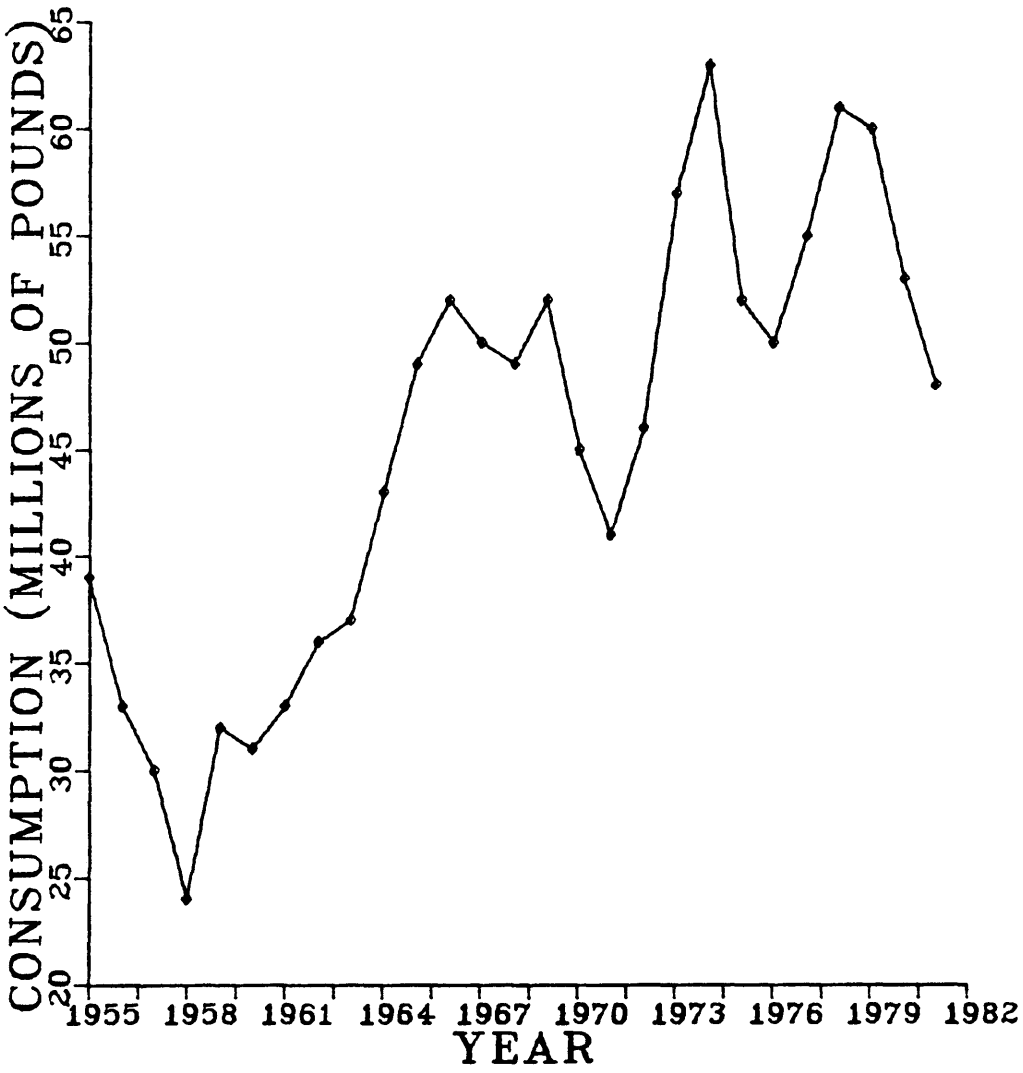


TABLE 5.6

Average Annual Growth Rates for World Steel Production, World Copper Production, and U.S. Alloy Steel Production, (in percent)

	1961-1970	1971-1980
World Steel Production	5.2	2.3
World Copper Production	4.4	2.4
U.S. Alloy Steel Production	5.1	1.7

World molybdenum consumption varies directly with world copper and steel production, as shown by equation (3-1):

$$Y = -57.03 + .0137\ (\text{World Copper Production}) + .211\ (\text{World Steel Production}) \qquad (3\text{-}1)$$

As was explained in section 5.2, world steel production is expected to grow as the economy improves. World copper production does not look promising in the short term; however, neither producers or consumers have large stockpiles of the metal. Copper production will increase as the recession ends, but it generally lags behind the economy by about a year. Again, the assumed growth rates for the independent variables have been listed along with forecast values in Table 5.7, making it possible for the reader to adjust the forecasts to his liking.

TABLE 5.7

Multiple Regression Forecasts for World Molybdenum Consumption

	Average Annual Growth Rate (percent)	1982	1983	1984	1985	1986	1987
World Copper Production (thousands of tons)	2.0	5,900	6,136	6,259	6,384	6,512	6,707
World Steel Production (millions of tons)	2.0	770	785	801	817	833	850
World Molybdenum Consumption Forecast (millions of pounds)		186	193	198	203	208	214
95 Percent Confidence Interval Bounds (millions of pounds)		72,300	79,307	83,312	89,317	94,322	100,328

U.S. molybdenum consumption depends solely on U.S. alloy steel production, as shown by equation (3-2):

$$Y = 10410 + 2.8 \text{ (U.S. Alloy Steel Production)} \quad (3\text{-}2)$$

As was stated in the previous section, section 5.3, U.S. alloy steel production rose 3.8 percent in 1981. A graph of U.S. alloy steel production, Figure 5.5, seems to indicate it reached the bottom of its 5-year cycle in 1980. Table 5.8 lists both the forecast values and the assumed growth rate.

The 24 month forecasts that were obtained by using the Box-Jenkins model for U.S. molybdenum consumption, are listed in Table 5.9. Equation (3-3) was used to generate the forecasts:

$$(1-B)(1+.7251B)X_t = (1.7428B)(1-.8812B^{12})e_t \quad (3\text{-}3)$$

Summing the 12 monthly forecasts make it possible to compare Box-Jenkins forecasted values with the multiple regression forecasts for U.S. molybdenum consumption listed in Table 5.8. The Box-Jenkins forecast for 1982 is 52 million pounds, close to the multiple regression value of 56.3 million pounds. The 1983 Box-Jenkins value is 43 million pounds, below the multiple regression value of 57.2 million pounds. It should be pointed out that both values fall within each other's 95 percent confidence interval bounds.

TABLE 5.8

Multiple Regression Forecasts for U.S. Molybdenum Consumption

	Average Annual Growth Rate (percent)	1982	1983	1984	1985	1986	1987
U.S. Alloy Steel Production (thousands of tons)	2.0	16,400	16,700	17,100	17,400	17,700	18,100
U.S. Molybdenum Consumption Forecast (millions of pounds)		56.3	57.2	58.3	59.1	60.0	61.1
95 Percent Confidence Interval Bounds (millions of pounds)		34.6, 78	35.5, 78.9	36.6, 80	37.4, 80.8	38.3, 81.7	39.4, 82.8

TABLE 5.9

Box-Jenkins Forecasts for U.S. Molybdenum Consumption

		Forecast Value (thousands of pounds)	95 Percent Confidence Interval Bounds (thousands of pounds)	
1982	January	4,874	2,465,	7,283
	February	4,188	1,715,	6,661
	March	5,004	2,513,	7,494
	April	4,830	2,335,	7,326
	May	5,291	2,794,	7,787
	June	3,979	1,482,	6,476
	July	3,211	714,	5,708
	August	2,675	178,	5,172
	September	4,396	1,899,	6,893
	October	4,439	1,942,	6,936
	November	4,372	1,875,	6,869
	December	4,553	2,056,	7,050
1983	January	4,088	1,573,	6,604
	February	3,475	959,	5,992
	March	4,253	1,736,	6,769
	April	4,099	1,583,	6,616
	May	4,549	2,032,	7,066
	June	3,243	726,	5,759
	July	2,472	-45,	4,989
	August	1,937	-580,	4,454
	September	3,658	1,141,	6,175
	October	3,701	1,184,	6,218
	November	3,634	1,117,	6,151
	December	3,815	1,298,	6,332

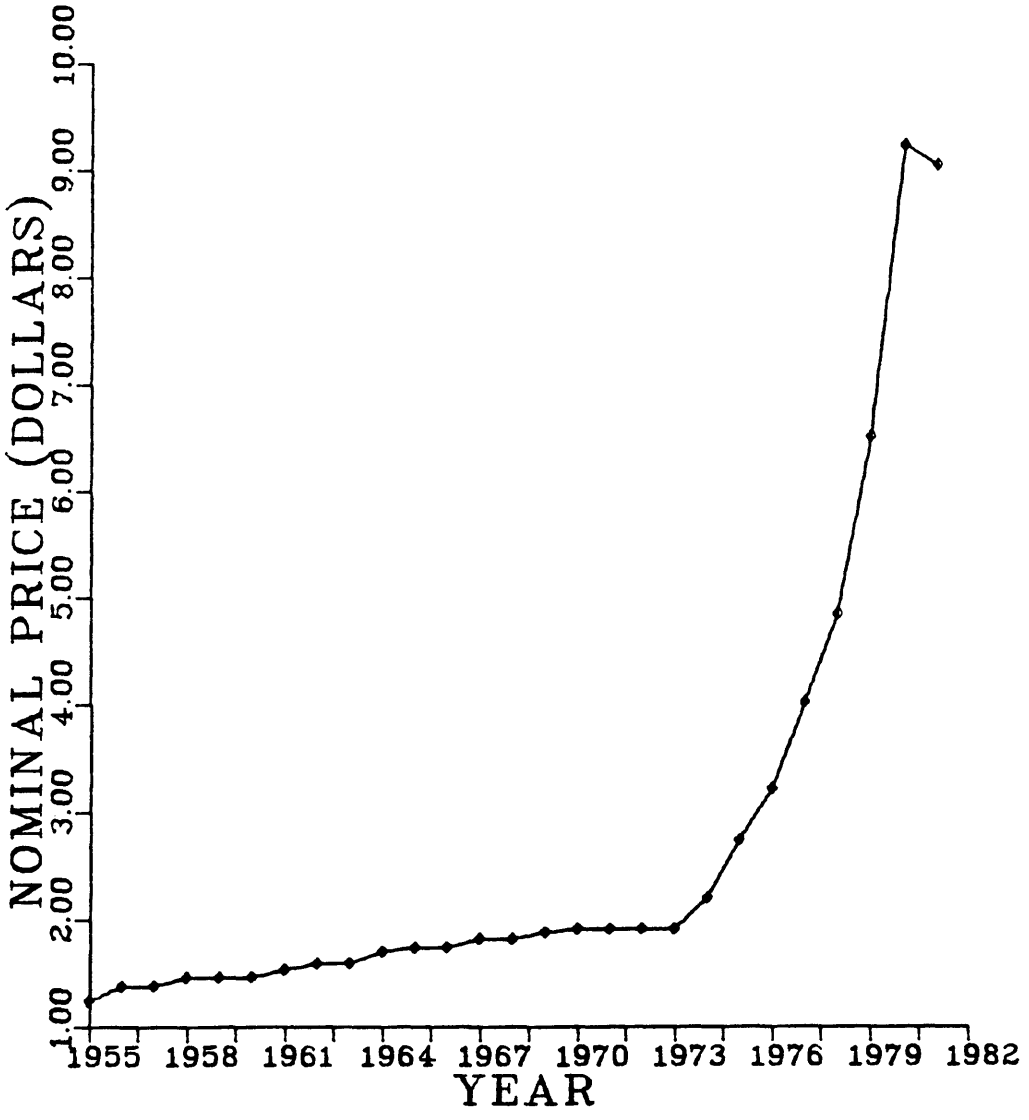
5.5 Forecasts for Molybdenum Price

The nominal price for molybdenum grew slowly in the 1960's; its annual average growth rate was 2.6 percent a year. The 1970's saw a large increase in the nominal price for molybdenum, averaging 14 percent a year. This

rapid growth can be seen in Figure 5.9, a graph of molybdenum nominal price over time.

FIGURE 5.9

MOLYBDENUM NOMINAL PRICE



The nominal price for molybdenum declined by 2.1 percent in 1981, for the first time in 20 years.

Real molybdenum price was obtained by dividing the nominal price by the Producer Price Index (PPI). The PPI is graphed over time in Figure 5.10, while real molybdenum price is graphed over time in Figure 5.11.

FIGURE 5.10

PRODUCER PRICE INDEX

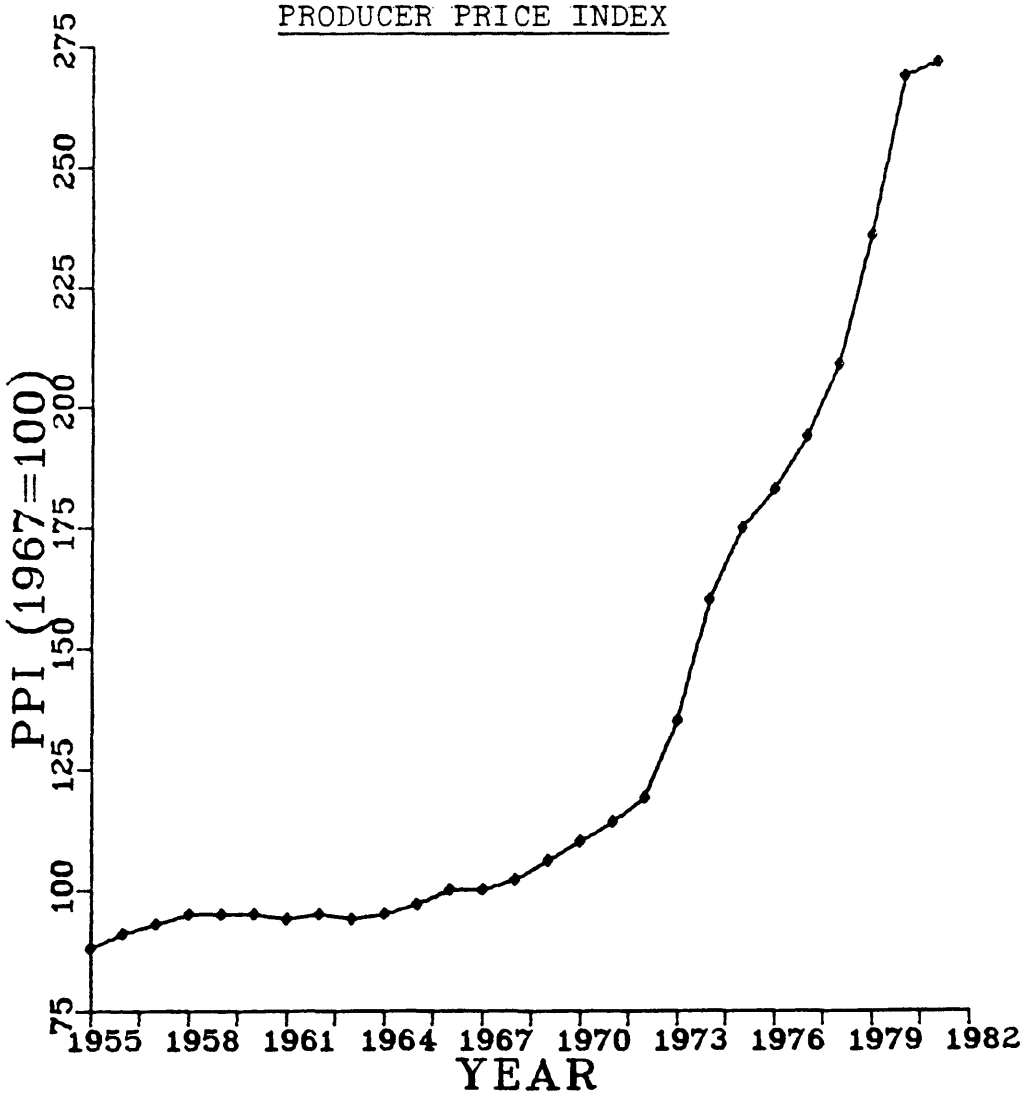
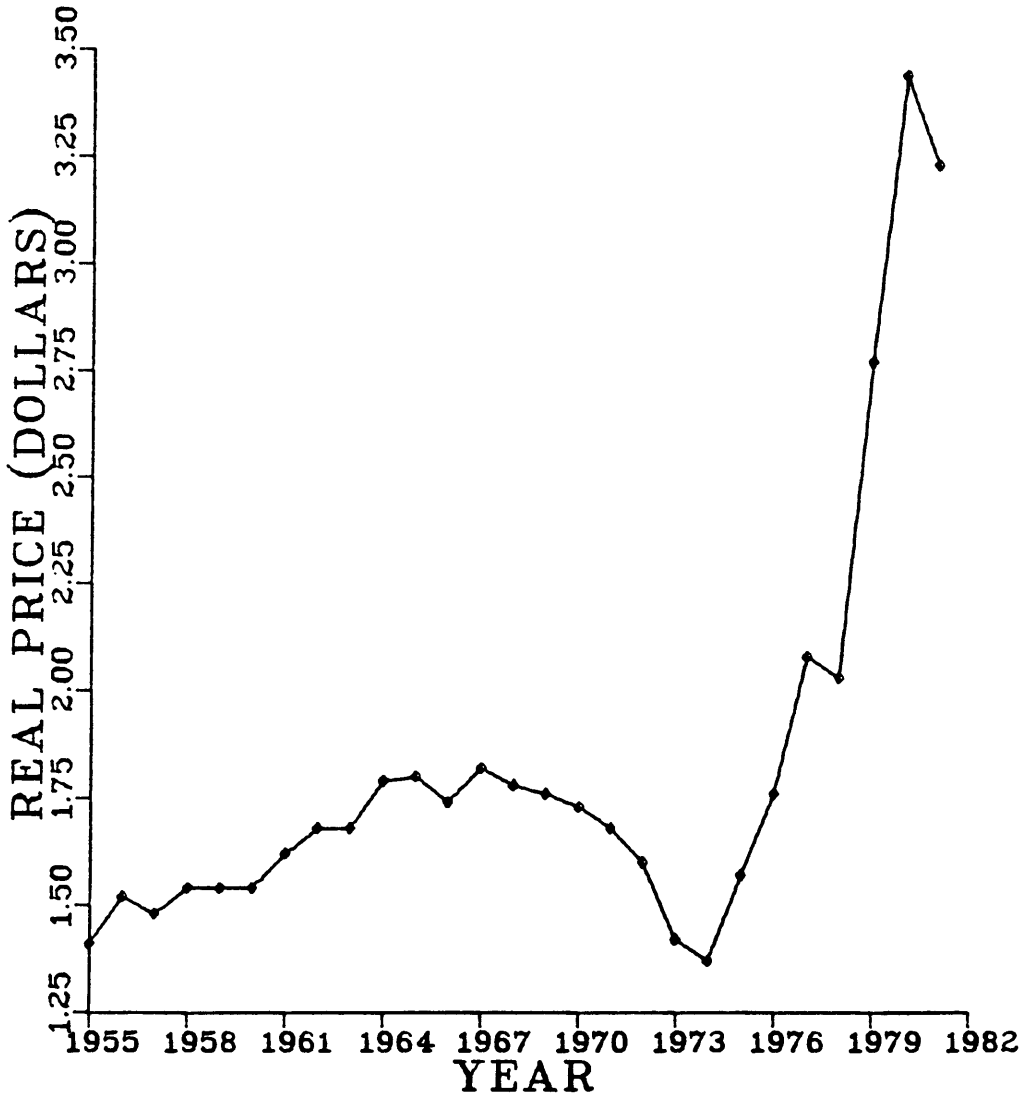


FIGURE 5.11

MOLYBDENUM REAL PRICE



Real price exhibited relatively slow growth through 1967. From 1967 through 1974, real molybdenum price declined every year. Real molybdenum price grew rapidly from 1974 through 1981. Even with real price declining from 1971 to 1974, it grew an average of 6 percent a year for the decade. The reader is referred back to the growth rates listed in Table 5.1 at the beginning of this chapter. In 1981, real producer price for molybdenum declined by 3.5 percent.

As was explained in section 4.6 of this thesis, the multi-tiered pricing system that was established in 1979 to protect North American consumers from changes in the world molybdenum market, has been breaking down due to the current oversupply of molybdenum. Producers no longer control 85 percent of the molybdenum market. Europe is currently purchasing all of its molybdenum on the free market, the U.S. and Canada are purchasing 20 percent of their molybdenum on the free market, and Japan is purchasing 30 percent on the free market. The decline in molybdic oxide prices was described in detail in section 4.3 of Chapter 4. Producers have been selling their molybdenum between list price and dealer price. These conditions are not expected to continue once demand for molybdenum rises; hence, domestic producer price for molybdic oxide

is still the quantity being forecast.

As producer stocks lessen, molybdenum prices should stabilize. To achieve a significant reduction in stocks, demand must increase. As was mentioned in the two previous sections, 5.3 and 5.4, economic indicators are beginning to suggest that the recession is ending, and that we are moving towards recovery. Even after the steel industry begins to recover, it will probably take almost a year to get rid of the current producer stocks. Molybdenum prices will probably begin to stabilize in mid- to late-1983.

Growth rates for the independent variables used in the multiple regression equations for both nominal and real molybdenum price are listed in Table 5.10.

TABLE 5.10

Average Annual Growth Rates U.S. Molybdenum Consumption, U.S. Aerospace Sales, U.S. Machine Tool Orders, and Nickel Producer Price (in percent)

	1961-1970	1971-1980
U.S. Molybdenum Consumption	3.4	1.6
U.S. Aerospace Sales	7.4	7.9
U.S. Machine Tool Orders	2.7	14.8
Nickel Producer Price[1]	5.2	8.6

[1]Nickel producer price is the average annual price for nickel cathodes.

The regression equation for nominal price showed it to be directly related to U.S. aerospace sales, nickel producer price, and U.S. machine tool orders, as shown in equation (4-1):

$$Y = 1.94 \times 10^{-4}(\text{U.S. Aerospace Sales}) + .591(\text{Nickel Producer Price}) - 7.78 \times 10^{-5}(\text{U.S. Molybdenum Consumption}) + 8.63 \times 10^{-4}(\text{U.S. Machine Tool Orders}) \quad (4\text{-}1)$$

Nominal price is also inversely related to U.S. molybdenum consumption. Aerospace sales increased by over 15 percent in 1981; with the scheduled growth in the U.S. defense budget, they will continue to increase. Nickel producer price rose by only .6 percent in 1981. Nickel is used pirmarily in alloy steels; as the recession ends, nickel's price should rise as steel production increases. U.S. machine tool orders are highly dependent on the level of capital investment. Due to the high interest rates, machine tool sales have been dropping; they decreased by 42 percent in 1981. Interest rates are expected to begin falling as the U.S. pulls out of the current recession (Rocky Mountain News, July 1, 1982, p. 1). The values that were forecast for U.S. molybdenum consumption in section 5.4 will be used in the price forecasts.

The assumed annual growth rates for the independent

TABLE 5.11

Multiple Regression Forecasts for Nominal Molybdenum Price

	Average Annual Growth Rate (percent)	1982	1983	1984	1985	1986	1987
U.S. Aerospace Sales (millions of dollars)	10.0	85,360	93,896	98,591	103,520	108,696	119,565
Nickel Producer Price (dollars)	5.0	3.20	3.36	3.53	3.70	3.89	4.08
U.S. Molybdenum Consumption Forecast (thousands of pounds)		56,300	57,200	58,300	59,100	60,000	61,100
U.S. Machine Tool Orders (millions of dollars)	7.5	1,671	1,796	1,931	2,075	2,231	2,399
Nominal Molybdenum Price Forecast (dollars)		7.49	8.48	9.08	9.73	10.43	11.69
95 Percent Confidence Interval Bounds (dollars)		2.49, 12.49	3.48, 13.48	4.08, 14.08	4.73, 14.73	5.43, 15,43	6.69, 16.69

variables are listed along with the forecast values in Table 5.11.

Using the Box-Jenkins model for nominal price, equation (4-3), 24 monthly forecasts were obtained.

$$(1-B)(1+.7251B)X_t = (1+.7428B)(1-.8812B^{12})e_t \qquad (4-3)$$

They are listed below in Table 5.12.

TABLE 5.12

Box-Jenkins Forecasts for Nominal Molybdenum Price

		Forecast Value (dollars)	95 Percent Confidence Interval Bounds (dollars)	
1982	January	8.60	7.90	9.20
	February	8.60	8.00	9.20
	March	8.60	8.00	9.30
	April	8.70	8.00	9.30
	May	8.70	8.00	9.30
	June	8.70	8.00	9.30
	July	8.80	8.10	9.40
	August	8.60	7.90	9.20
	September	8.70	8.00	9.30
	October	8.90	8.20	9.50
	November	9.00	8.40	9.60
	December	9.00	8.40	9.70
1983	January	9.10	8.50	9.70
	February	9.10	8.50	9.80
	March	9.20	8.50	9.80
	April	9.20	8.60	9.80
	May	9.20	8.60	9.80
	June	9.20	8.60	9.80
	July	9.30	8.70	9.90
	August	9.10	8.50	9.70
	September	9.20	8.60	9.80
	October	9.40	8.80	10.00
	November	9.60	8.90	10.20
	December	9.60	8.90	10.20

The forecast values for January through June of 1982 are higher than the actual values have been. This is because the current list price for molybdenum is nominal, or above the actual selling price. The multiple regression forecast for 1982 is closer to the true selling price for domestic molybdic oxide. As the molybdenum price stabilizes, the forecast values for molybdic oxide will be closer to the actual values.

Real molybdenum price depends on U.S. aerospace sales, U.S. molybdenum consumption, and U.S. machine tool orders, as shown in equation (4-2):

$$Y = .0189 - 2.378 \times 10^{-7}(\text{U.S. Molybdenum Consumption}) + 2.74 \times 10^{-7}(\text{U.S. Aerospace Sales}) + 2.38 \times 10^{-6}(\text{U.S. Machine Tool Orders}) \quad (4\text{-}2)$$

Since these are 3 of the same variables used to forecast nominal molybdenum price, the growth rates are expected to be the same. The forecast values are listed in Table 5.13.

The 12 monthly forecasts that were obtained by using the Box-Jenkins model for real molybdenum price, equation (4-4), are listed in Table 5.14.

$$(1-B)(1+.3371B)(1+1.7548B^{12}-.8774B^{24})X_t = (1+.6378B)e_t \quad (4\text{-}4)$$

TABLE 5.13

Multiple Regression Forecasts for Real Molybdenum Price

	Average Annual Growth Rate (percent)	1982	1983	1984	1985	1986	1987
U.S. Molybdenum Consumption Forecast (thousands of pounds)		56,300	57,200	58,300	59,100	60,000	61,100
U.S. Aerospace Sales (millions of dollars)	10.0	85,360	93,896	98,591	103,520	108,686	119,565
U.S. Machine Tool Orders (millions of dollars)	7.5	1,671	1,796	1,931	2,075	2,231	2,399
Real Molybdenum in Price Forecast (dollars)		3.29	3.53	3.66	3.81	3.97	4.28
95 Percent Confidence Interval Bounds		2.16, 4.42	2.40, 3.66	2.53, 4.79	2.68, 4.94	2.84, 5.10	3.15, 5.41

TABLE 5.14

Box-Jenkins Forecasts for Real Molybdenum Price

		Forecast Value (dollars)	95 Percent Confidence Interval Bounds (dollars)	
1982	January	2.90	2.50	3.40
	February	2.10	1.70	2.60
	March	3.40	3.00	3.90
	April	.90	.40	1.40
	May	3.10	2.60	3.50
	June	1.70	1.30	2.20
	July	2.10	1.70	2.60
	August	2.20	1.70	2.60
	September	2.60	1.20	2.10
	October	2.00	1.50	2.50
	November	.90	.40	1.30
	December	2.10	1.70	2.60

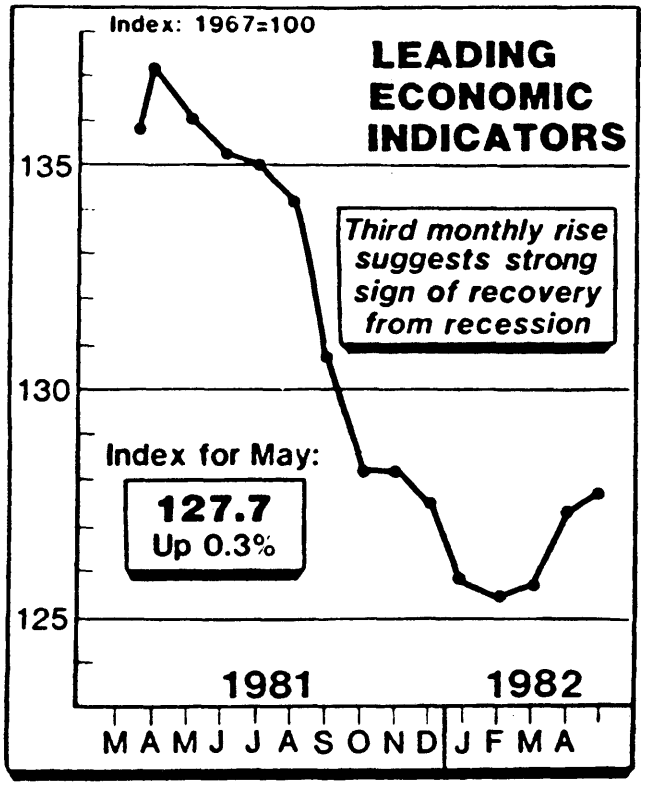
5.6 The Molybdenum Market

As was mentioned in the previous sections of this chapter, there are signs indicating that the current recession has reached bottom, and that recovery has begun. In early July of 1982, the Commerce Department announced that its index of leading economic indicators had risen for the third straight month in May (Rocky Mountain News, July 1, 1982, p. 3). A graph of the index is shown in Figure 5.12.

Another major reason for believing that the recession has bottomed is that business inventories were cut substantially in the first three months of 1982. During

FIGURE 5.12

LEADING ECONOMIC INDICATORS



SOURCE: Rocky Mountain News, July 1, 1982, p. 3.

the first quarter, inventories were cut at an annual rate of $17.5 billion, the largest inventory reduction since World War II (Wall Street Journal, June 14, 1982, p. 1). As a result of this inventory cut, most of the goods being sold will come from new production. Other indicators

that show improvement include car sales, which rose by 5.9 percent in May, and an increase in new building permits (Wall Street Journal, June 14, 1982, p. 1).

The 10 percent tax cut, which takes effect July 1, 1982, is also expected to encourage consumer spending. The tax cut, which is predicted to total $39 billion, combined with a 7.4 percent increase in Social Security benefits, should put around $1 billion a week into the economy (Rocky Mountain News, July 1, 1982, p. 3).

Many analysts are hesitant to predict a full, rapid, recovery; however, the political implications of economic recovery should not be overlooked. With a presidential election in 1984, it is probably in Reagan's best interest to make sure that the U.S. economic situation has improved.

How quickly the molybdenum market recovers from the current slump depends on how fast the economy recovers. With its large producer stocks, molybdenum will lag behind any growth in steel production. Molybdenum will probably lag behind the general economy by about a year to a year and a half.

The current oversupply in molybdenum can be attributed to overinvestment in molybdenum exploration and development projects in the late 1970's. Both the nominal price and real price for molybdenum rose sharply after 1974 in response

to the increased demand for new, lighter steels after the energy crisis. and to increased Soviet bloc demand. Analysts were predicting that the demand for molybdenum would grow at 7 to 8 percent throughout the 1980's (Duval, 1981. p. B28). That level of growth has not been maintained; it appears a 2 to 3 percent growth in molybdenum consumption is more likely.

The increase in price, which caused overinvestment in molybdenum properties, was due to a change in market structure. In 1960, AMAX controlled 60 percent of world molybdenum production, and the price (Sutulov, 1981, p. 69 - 71). AMAX was very conservative in its pricing policy; it merely attempted to keep up with inflation, and to make a reasonable profit. By the late 1970's, AMAX produced only 40 percent of the world's molybdenum (Sutulov, Volume I, 1978, p. 23). This means that in 1979, AMAX controlled about the same proportion of the market that by-product producers controlled. Free market prices rose sharply due to the Canadian strike and to the increased Soviet bloc demand. By that time, there were enough other producers in the market to force AMAX to raise its prices also. Producer prices followed dealer prices to record highs. As demand diminished, AMAX was forced

to lower its prices for the first time in 20 years. AMAX currently lists Climax molybdic oxide at $8.50 a pound, but the price is nominal, meaning that no appreciable amount is being sold at that price.

It is important to remember that primary molybdenum producers and by-product producers have substantially different approaches to production levels and pricing. By-product producers view molybdenum as supplemental income. They are more than willing to speculate on molybdenum prices, whereas, primary producers need stable market prices to assure that their production levels can be maintained. Once their capital investment in the recovery circuit has been recovered, it costs by-product producers very little to produce molybdenum; they will always be able to undercut primary producer prices.

Another important factor to consider is the manner in which South American countries view the market. Both Chile and Peru heavily depend on metals production for their balance of trade. They are virtually willing to sell at any price; any income to them is better than none. Chile and Peru produce around 10 percent of the world's molybdenum.

Sutulov estimates that the molybdenum market can support one new large mine, about the size of Henderson, every

10 years (Sutulov, Volume III, 1980, p. 246). With current world production capacity at nearly 300 million pounds, and an additional 45 million pounds coming on stream in 1983-1984, it is doubtful that anyone would develop a large deposit, like U.S. Borax's Quartz Hill, during the 1980's. World demand for molybdenum has been near 200 million pounds since 1978. Assuming that world demand will grow at approximately 3 percent annually, another large deposit would not need to be developed until the early to mid-1990's. This stretches Sutulov's 10 years to at least 15 years.

Investors want to be sure that the market will be able to absorb the new production, because the costs involved are substantial. It is estimated that Quartz Hill would cost nearly $900 million to develop. A medium-size deposit, like Goat Hill, costs between $200 million to $300 million to develop, while adding a by-product circuit to a copper mine costs only $20 million. Developing a medium-size molybdenum mine, or adding a by-product circuit, are much safer investments than large primary molybdenum mines.

Molybdenum has a relatively stable demand; it is an important alloying agent and new uses, like semi-conductors, will continue to develop. It is unfortunate that overinvest-

ment in molybdenum properties caused by a temporary price increase in the late 1970's has flooded the market with excess molybdenum; however, as the recession ends, the demand for molybdenum will begin to grow again. Demand will increase at a much slower rate than was forecast in the late 1970's, probably at around 3 percent a year. Since the demand for molybdenum closely follows the steel cycle, and since the recession appears to have bottomed out in March of 1982, the molybdenum market should recover from its current slump in 1985-86.

CHAPTER 6

SUGGESTIONS FOR FURTHER STUDY

While studying the market for molybdenum, numerous questions outside the scope of this thesis developed. The purpose of this chapter is to suggest a few of the topics that would merit further study.

The future of the multi-tiered pricing system for molybdenum could be studied in greater depth. The question of whether or not domestic and export prices should exist could also be explored. It would be interesting to do a detailed comparison of dealer and producer prices over time.

The cyclicality of mineral commodities leads to many intriguing topics. Mineral commodities seem to have an enhanced cyclicality; they seem to hit higher peaks and lower troughs than the rest of the economy. Studying how financial planning could help alleviate the cycles would be exceptionally valuable to the mining industry.

Removing time period bias from forecasting would be helpful. The term time period bias refers to people viewing the future simply as an extension of the present. If the market is doing well, they expect it to continue

indefinitely. This often leads to naive forecasts; an example of this would be growth rates for molybdenum for the late 1970's.

This is just a brief outline of possible topics. Many other interesting topics exist in the area of mineral commodity forecasting.

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APPENDIX A

U.S. REGRESSION DATA DESCRIPTIONS

The data used to formulate the U.S. regression equations were collected on a yearly basis for the 27-year period from 1955 through 1981. The sources for the 19 variables used in the analysis are listed below.

The first 5 variables were taken from the Minerals Yearbook (1955 - 1980) published by the Bureau of Mines of the U.S. Department of the Interior. The data for 1981 were obtained from the January 1982 issue of the Mineral Industry Surveys for Molybdenum which is also published by the Bureau of Mines.

1) U.S. Molybdenum Production

   Molybdenum production refers to molybdenite concentrate production, however, it is reported in thousands of pounds contained molybdenum. Since the Bureau of Mines reports all of its statistics in thousands of pounds contained molybdenum, it is possible to compare production, consumption, and stocks figures, even though they refer to different molybdenum product forms.

2) U.S. Molybdenum Consumption

   Consumption refers to the amount of molybdenite

concentrate converted to molybdic oxide. Again, consumption is reported in thousands of pounds contained molybdenum.

3) U.S. Molybdenum Stocks

Molybdenum stocks refer to stocks held at both mine and plant; they are listed in thousands of pounds contained molybdenum.

4) U.S. Molybdenum Price

Annual average price for domestic bagged molybdenum was computed from monthly quotations published in Engineering and Mining Journal (EMJ). Price is listed in dollars per pound.

5) Producer Price for Nickel Cathodes

Annual average price for nickel cathodes was computed from montly quotations published in EMJ. Price is listed in cents per pound.

The next 3 variables were taken from Metal Statistics (1960 - 1981) published in New York by Fairchild Publications for American Metal Market.

6) Producer Price for Electrolytic Copper Wirebar

The annual average producer price for electrolytic copper wirebar is listed in cents per pound. The annual averages were computed from daily quotations in American Metal Market.

7) U.S. Alloy Steel Production

Alloy steel production refers to production of ingots and steel for castings, as reported by the American Iron and Steel Institute; the data are in thousands of net tons (2,000 pounds).

8) U.S. Stainless Steel Production

Stainless steel production refers to production of stainless steel ingots, including steel for casting, as reported by the American Iron and Steel Institute; the data are in thousands of net tons (2,000 pounds).

The next 10 variables were taken from Business Statistics (1975 - 1981) published by the Bureau of Economic Analysis of the U.S. Department of Commerce.

9) Total Domestic Retail Car Sales

Total domestic retail car sales are defined to be the number of cars delivered to customers by franchised dealers. The information was gathered by the Motor Vehicle Manufacturers Association of the United States. The data are in thousands of cars.

10) Net Shipments of Pipe and Tubing

Pipe and tubing refers to all standard and line pipe, oil country goods, mechanical, pressure,

and structural pipe and tubing. The information was gathered by the American Iron and Steel Institute; it represents nearly 100 percent of the total industry production. The data are in thousands of short tons.

11) Net Shipments of Rails and Accessories

Rails and accessories refers to all rails, tie plates, rolled and forged wheels, axles, joint bars and track spikes. Again, the information was gathered by the American Iron and Steel Institute; it represents nearly 100 percent of the total industry production. The data are in thousand of short tons.

12) Refined Primary Copper Production from Domestic Ores

Primary refinery production figures were gathered by the Bureau of Mines; they represent the total refined copper produced at primary plants from domestic ores. The figures are in thousands of short tons.

13) Total Domestic Product Demand for Oil

The information was gathered by the Bureau of Mines and is equal to total product demand minus exports. The figures are in millions of barrels.

14) Total Net Sales of Aerospace Vehicles

Figures were gathered by the U.S. Bureau of the Census of the Department of Commerce. The data are based on reports from companies whose principle business is the development and production of aircraft, aircraft engines, missle and spacecraft engines, missles, and spacecraft. The figures are in millions of dollars.

15) Total New Construction

Total new construction data were also gathered by the Bureau of the Census. They include both private and public construction of new buildings, or structures other than buildings, i.e., essential service facilities and utilities. The figures are in millions of dollars.

16) Total New Orders for Machine Tools (Metal Cutting Type Tools)

Figures were collected by the National Tool Builder's Association; the data represent approximately 80 percent of the total industry. Machine tools for metal cutting are defined to be power driven, not portable by hand, and are complete metal-working machines; examples would be presses and forging machines. Figures are in millions of dollars.

17) Metal Mining Index

The index was calculated by the Division of Research and Statistics of the Board of Governors of the Federal Reserve System; it uses 1967 as its base year. The index measures changes in the physical volume, or quantity, of metals mined.

18) Producer Price Index

The index was calculated by the Bureau of Labor Statistics of the U.S. Department of Labor; it uses 1967 as its base year. The index is designed to show the rate and direction of price movements for all commodities in primary markets. Prices used in calculating the index represent the first important commercial transaction for the commodities.

19) National Defense Outlays

National defense spending figures were taken from the Statistical Abstract of the United States 1981 published by the Bureau of the Census of the U.S. Department of Commerce. The figures are in billions of dollars.

APPENDIX B

WORLD REGRESSION DATA DESCRIPTIONS

The data used to formulate the world regression equations were collected on a yearly basis for the 24-year period from 1957 through 1980. The sources for the 8 variables used in the analysis are listed below.

1) World Molybdenum Production

   World molybdenum production was taken from the Minerals Yearbook (1957 - 1980) published by the Bureau of Mines of the U.S. Department of the Interior. It is reported in thousands of pounds contained molybdenum.

2) World Molybdenum Consumption

   World molybdenum consumption was taken from the March issues of Engineering and Mining Journal (EMJ, 1958 - 1981). Each March, EMJ reviews mineral commodities by asking industry representatives to analyze their commodity's performance in the previous year. Representatives of AMAX, Inc. have almost always written the molybdenum commodity summary; hence, consumption figures for molybdenum are AMAX's approximation of world consumption. Figures are in millions of pounds.

3) Molybdenum Price

Annual average prices for domestic bagged molybdenum were taken from the Minerals Yearbook (1957 - 1980). The price listed in the Minerals Yearbook was computed from monthly quotations published in EMJ. Domestic price was used as world price because the split in domestic and export prices did not occur until 1978. With the vast over-supply of molybdenum, two-tiered prices are not expected to continue.

4) World Nickel Production

World nickel production figures were also taken from the Minerals Yearbook (1957 - 1980). The figures are listed in short tons of nickel.

The last 4 variables were taken from Metal Statistics (1960 - 1981) published in New York by Fairchild Publications for American Metal Market.

5) World Refined Copper Production

World refined copper production refers to refinery output as reported by the American Bureau of Metal Statistics; the figures are in tons of 2,000 pounds. Coverage represents about 90 percent of the Free World.

6) Producer Price for Electrolytic Copper Wirebar

Copper price is the annual average price for electrolytic copper wirebar; the figures are in cents per pound. The annual averages were computed from daily quotations in the American Metal Market.

7) World Production of Steel

World steel production refers to production of steel ingots and castings, as reported by the American Iron and Steel Institute; the data are in million of net tons (2,000 pounds).

8) U.S. Percentage of Alloy Steel Production to Total Steel Production

The percentage of alloy steel production to total steel output was computed by the American Iron and Steel Institute. Although the U.S. percentage of alloy steel production is not equal to the world percentage of alloy steel output, the U.S. percentage is being used as a proxy for world percentage to indicate the growth in alloy steel production.

APPENDIX C

BOX-JENKINS DATA DESCRIPTIONS

The data used for the Box-Jenkins forcasting method was collected on a monthly basis for the 8-year period from 1974 through 1981. The sources for the data are listed below.

1) Molybdenum Price

Monthly prices for domestic bagged molybdic oxide were taken from Metal Statistics (1975 - 1981) published in New York by Fairchild Publications. The monthly average prices were compiled from quotations listed in American Metal Market.

The last 3 variables were taken from Mineral Industry Surveys for Molybdenum (January 1974 - December 1981) which are published on a monthly basis by the Bureau of Mines of the U.S. Department of the Interior. The data were gathered from U.S. molybdenum producers by the Bureau of Mines

2) U.S. Molybdenum Production

Molybdenum production refers to molybdenite concentrate production, however, it is reported in thousands of pounds contained molybdenum. Since the Bureau of Mines reports all of its statistics

in thousands of pounds contained molybdenum, it is possible to compare production, consumption, and stocks figures, even though they refer to different molybdenum product forms.

3) U.S. Molybdenum Consumption

Consumption refers to the amount of molybdenite concentrate converted to molybdic oxide. Again, consumption is reported in thousands of pounds contained molybdenum.

4) U.S. Molybdenum Stocks

Molybdenum stocks refer to stocks held at both mine and plant; they are listed in thousands of pounds contained molybdenum.

APPENDIX D

U.S. MOLYBDENUM DATA (MONTHLY)

	Molybdenum Nominal Price for Bagged Oxide (dollars per pound)	Molybdenum Production (thousands of pounds)	Molybdenum Consumption (thousands of pounds)	Molybdenum Stocks, Mine and Plant (thousands of pounds)	Producer Price Index All Commodities (1967=100)
1974					
Jan	1.91	9,578	6,767	20,147	146.6
Feb	1.91	9,501	6,929	23,243	149.5
Mar	1.91	9,817	8,096	19,872	151.4
Apr	1.91	9,092	7,886	18,976	152.7
May	2.07	10,318	8,001	17,443	155.0
June	2.07	10,036	7,085	17,993	155.7
July	2,27	8,745	6,946	14,889	161.7
Aug	2.27	9,471	6,512	18,494	167.4
Sept	2.41	9,578	8,024	19,477	167.2
Oct	2.55	9,155	7,651	17,397	170.2
Nov	2.55	9,872	12,852	15,487	171.9
Dec	2.55	8,065	12,861	13,319	171.5
1975					
Jan	2.69	8,903	12,323	14,417	171.8
Feb	2.69	8,450	13,318	10,880	171.3
Mar	2.69	8,989	8,941	11,235	170.4
Apr	2.69	9,569	8,381	11,455	172.1
May	2.69	9,450	8,769	12,366	173.2
June	2.69	8,858	7,838	11,399	173.7
July	2.69	7,803	5,750	13,551	175.7
Aug	2.69	8,511	5,896	13,549	176.7
Sept	2.69	8,639	6,257	13,912	177.7
Oct	2.90	9,004	7,013	11,969	178.9
Nov	2.90	9,317	6,221	13,060	178.2
Dec	2.90	8,908	7,625	11,917	178.7
1976					
Jan	2.90	9,296	6,962	13,317	179.4
Feb	2.90	9,018	6,580	14,582	179.4
Mar	2.90	9,716	7,230	13,900	179.7
Apr	3.20	9,289	7,418	12,427	181.3
May	3.20	9,934	7,438	13,680	181.9
June	3.20	8,965	6,799	13,236	183.2
July	3.20	7,906	7,625	12,127	184.4
Aug	3.20	8,972	4,320	12,768	183.8
Sept	3.31	9,147	7,257	13,175	184.4
Oct	3.53	10,353	8,136	12,238	185.3
Nov	3.53	10,014	7,505	11,299	185.6
Dec	3.58	9,969	7,591	9,656	187.1

APPENDIX D

U.S. MOLYBDENUM DATA (MONTHLY)

	Molybdenum Nominal Price for Bagged Oxide (dollars per pound)	Molybdenum Production (thousands of pounds)	Molybdenum Consumption (thousands of pounds)	Molybdenum Stocks, Mine and Plant (thousands of pounds)	Producer Price Index All Commodities (1967=100)
1977					
Jan	3.81	9,944	6,887	11,569	188.1
Feb	3.81	8,900	6,430	12,000	190.2
Mar	3.81	11,017	7,393	13,067	192.0
Apr	3.81	11,161	7,656	14,970	194.3
May	3.81	11,709	8,436	15,443	195.2
June	3.81	10,844	7,909	14,777	194.5
July	3.81	8,751	6,868	15,236	194.8
Aug	4.30	9,153	5,120	16,540	194.6
Sept	4.30	8,637	8,804	14,261	195.3
Oct	4.30	10,095	8,614	12,046	196.3
Nov	4.30	10,320	8,180	12,724	197.1
Dec	4.30	9,394	8,745	9,445	198.2
1978					
Jan	4.30	9,875	7,994	10,151	200.1
Feb	4.30	9,470	7,015	10,794	202.1
Mar	4.30	11,200	8,493	10,777	203.7
Apr	4.75	12,099	7,247	12,691	206.5
May	4.75	11,592	8,735	11,332	208.0
June	4.75	11,501	7,531	12,995	209.6
July	4.75	9,842	6,913	13,225	210.7
Aug	4.75	11,981	7,013	13,697	210.6
Sept	5.38	10,820	9,545	12,919	212.4
Oct	5.38	11,755	9,012	11,808	214.9
Nov	5.38	11,574	7,799	11,061	215.7
Dec	5.39	10,774	9,078	8,508	217.5
1979					
Jan	8.61	11,123	8,562	9,620	220.8
Feb	5.61	10,972	7,299	11,037	224.1
Mar	5.61	12,767	8,272	12,471	226.7
Apr	5.75	12,084	9,046	10,861	230.0
May	5.75	12,060	9,635	9,827	232.2
June	5.75	11,607	7,599	10,099	233.5
July	6.64	10,807	8,274	9,144	236.9
Aug	6.64	12,263	8,202	10,551	238.1
Sept	6.64	12,022	8,596	10,909	241.7
Oct	7.12	13,678	9,493	11,019	245.2
Nov	8.49	12,464	8,976	11,414	246.9
Dec	8.49	11,916	9,198	9,569	249.7

APPENDIX D

U.S. MOLYBDENUM DATA (MONTHLY)

	Molybdenum Nominal Price for Bagged Oxide (dollars per pound)	Molybdenum Production (thousands of pounds)	Molybdenum Consumption (thousands of pounds)	Molybdenum Stocks, Mine and Plant (thousands of pounds)	Producer Price Index All Commodities (1967=100)
1980					
Jan	8.49	12,534	8,972	11,456	254.9
Feb	8.66	11,926	8,768	11,042	260.2
Mar	9.91	13,262	10,475	13,571	261.9
Apr	9.24	12,606	9,961	13,700	262.8
May	9.24	13,411	10,991	11,636	264.2
June	9.24	12,255	9,145	10,180	265.6
July	8.99	10,815	7,848	10,812	270.4
Aug	8.99	11,726	7,857	11,897	273.1
Sept	8.99	11,802	8,319	12,728	274.1
Oct	9.69	12,738	9,571	14,124	277.0
Nov	9.69	12,284	9,082	15,654	278.4
Dec	9.69	13,157	8,409	17,467	280.8
1981					
Jan	9.69	12,912	8,156	15,513	284.8
Feb	9.69	11,453	6,816	16,755	287.6
Mar	9.34	12,771	8,429	20,526	290.3
Apr	9.34	11,640	8,377	21,303	293.4
May	9.34	11,778	8,204	21,110	294.1
June	9.34	11,100	6,624	23,317	294.8
July	9.34	10,686	5,157	26,098	296.2
Aug	8.49	11,729	5,097	28,449	296.2
Sept	8.49	10,911	7,063	27,599	295.5
Oct	8.49	11,585	5,989	30,927	296.0
Nov	8.49	11,229	5,613	33,347	295.5
Dec	8.49	9,509	5,199	35,538	295.9

APPENDIX E

WORLD MOLYBDENUM DATA

	World Molybdenum Production (thousands of pounds)	World Molybdenum Consumption (millions of pounds	Production Nominal Price for Bagged Oxide (dollars per pound)	World Refined Copper Production (tons)	Producer Price for Electrolytic Copper Wirebar (cents per pound)	World Steel Production (millions of tons)	U.S. Percentage of Alloy Steel to Total Steel (%)	World Nickel Production (short tons)
1957	76,200	61	1.38	3,035,588	30.17	321.7	7.0	314,000
8	57,700	45	1.46	2,811,108	26.31	298.9	6.7	245,000
9	70,200	61	1.46	2,926,657	30.99	337.2	8.3	314,000
1960	89,500	75	1.46	3,697,359	32.34	381.6	7.5	358,000
1	87,900	76	1.53	3,704,368	30.32	390.1	7.7	398,000
2	75,000	70	1.59	3,673,858	31.00	394.1	8.2	394,000
3	76,055	79	1.59	3,756,828	31.00	422.2	8.6	395,000
4	77,829	90	1.70	3,962,459	32.35	479.0	8.8	408,929
1965	98,460	100	1.74	4,143,344	35.36	503.1	10.1	468,347
6	124,967	111	1.74	4,092,693	36.00	519.1	10.2	454,912
7	126,416	112	1.82	3,640,217	38.10	547.6	9.9	485,723
8	125,735	123	1.82	4,084,740	41.17	582.5	10.5	547,960
9	159,470	140	1.88	4,626,214	47.43	632.0	10.5	532,537
1970	177,982	146	1.91	4,698,661	58.07	654.2	9.7	692,710
1	171,064	135	1.91	4,454,839	52.09	639.9	10.1	702,027
2	174,418	147	1.91	4,879,419	51.44	694.5	10.5	673,817
3	183,698	181	1.91	5,784,200	59.53	768.6	10.7	757,366
4	189,274	207	2.20	5,985,100	77.06	782.8	11.6	849,257
1975	176,713	168	2.74	5,416,600	64.53	712.0	13.0	890,532
6	195,473	177	3.22	5,896,700	69.62	745.6	11.2	873,357
7	209,724	182	4.03	5,993,500	66.72	741.8	12.2	886,738
8	220,922	200	4.85	6,079,200	66.53	790.6	13.3	727,936
9	229,384	205	6.51	6,158,300	92.75	824.5	13.2	753,214
1980	238,101	182	9.24	6,070,300	102.19	792.1	13.8	850,366

APPENDIX F

U.S. MOLYBDENUM DATA (YEARLY)

	U.S. Molybdenum Production (thousands of pounds)	U.S. Molybdenum Consumption (thousands of pounds)	U.S. Molybdenum Stocks (thousands of pounds)	Molybdenum Nominal Price for Bagged Oxide (dollars per pound)	Total Domestic Retail Sales of New Passenger Cars (thousands)	National Defense Outlays (billions of dollars)	Net Shipments Pipe and Tubing (thousands of short tons)	Net Shipments Rails and Accessories (thousands of short tons)	Producer Price Index (1967=100)
1955	61,781	38,799	2,370	1.24	7,408	39.8	9,836	2,132	87.8
6	57,462	33,497	2,920	1.38	5,844	40.8	10,198	2,293	90.7
7	60,753	30,016	7,093	1.38	5,796	41.9	10,875	2,265	93.3
8	41,069	24,231	5,643	1.46	4,289	42.9	6,748	989	94.6
9	50,956	32,350	4,074	1.46	5,486	44.1	8,311	1,189	94.8
1960	68,237	31,387	3,481	1.46	6,142	45.2	7,052	1,266	94.9
1	66,563	32,621	2,815	1.53	5,556	47.1	7,067	839	94.5
2	51,244	35,674	3,490	1.59	6,753	49.0	7,103	1,029	94.8
3	65,011	37,478	2,436	1.59	7,334	50.1	7,043	1,106	94.5
4	63,605	43,119	4,303	1.70	7,617	51.5	8,137	1,395	94.7
1965	77,372	48,621	4,208	1.74	2,763	47.5	8,689	1,523	96.6
6	90,532	52,324	3,433	1.74	8,377	54.9	9,233	1,776	99.8
7	90,097	49,506	9,919	1.82	7,568	68.2	8,969	1,434	100.0
8	93,447	49,271	12,208	1.82	8,625	78.8	10,078	1.462	102.5
9	99,807	51,622	8,398	1.88	8,464	79.4	9,232	1,514	106.5
1970	111,352	45,337	9,715	1.91	7,119	78.6	7,778	1,596	110.4
1	109,592	40,950	29,077	1.91	8,681	75.8	7,574	1,564	113.9
2	112,138	45,558	45,243	1.91	9,327	76.6	7,609	1,601	119.1
3	113,859	57,049	21,998	1.91	9,676	74.5	9,133	1,689	134.7
4	112.011	63,476	18,659	2.20	7,454	77.8	9,844	1,785	160.1
1975	105,980	51,743	10,680	2.74	7,053	85.6	8,228	1,965	174.9
6	113,233	50,448	9,390	3.22	8,611	89.4	6,265	2.017	183.0
7	122.408	54,557	9,161	4.03	9,109	97.5	7,490	1,863	194.0
8	131,843	61,091	8,980	4.85	9,312	105.2	8,399	1,703	209.3
9	143,967	60,388	9,520	6.51	8,232	117.7	8,242	2,026	235.6
1980	150,686	53,265	18,101	9.24	6,581	130.4	9,097	1,797	268.8
1	137,303	47,873	35,548	9.05	6,209	156.0*	10,286	1,458	272.3

*The 1981 value is estimated.

APPENDIX F

U.S. MOLYBDENUM DATA (YEARLY)

	Metal Mining Index (1967=100)	Refined Primary Copper Production from Domestic Ores (thousands of short tons)	Producer Price for Electrolytic Copper Wirebar (cents per pound)	Alloy Steel Production (thousands of tons)	Producer Price for Nickel Cathodes (cents per pound)	Total Domestic Demand for Oil (millions of barrels)
1955	91.1	997.5	37.51	9,438	0.64	3,086.2
6	95.2	1,080.2	42.00	9,072	0.65	3,211.7
7	102.0	1,050.2	30.17	7,865	0.74	3,215.3
8	88.9	1,001.6	26.31	5,769	0.74	3,328.0
9	85.6	796.5	30.99	7,776	0.74	3,577.3
1960	111.5	1,121.3	32.34	7,416	0.74	3,585.8
1	102.8	1,181.0	30.32	7,540	0.78	3.641.3
2	104.8	1,214.1	31.00	8,083	0.80	3,796.0
3	103.3	1,219.3	31.00	9,343	0.79	3,921.4
4	112.3	1,259.9	32.35	11,191	0.79	4,034.2
1965	114.8	1,335.7	35.36	13,318	0.79	4,202.0
6	120.4	1,353.1	36.00	13,718	0.79	4,410.8
7	100.0	846.6	38.10	12,572	0.87	4,584.5
8	111.0	1,160.9	41.17	13,761	0.94	4,901.8
9	125.1	1,468.9	47.43	14,861	1.05	5,159.9
1970	131.9	1,521.2	58.07	12,824	1.29	5,364.5
1	120.6	1,410.5	52.09	12,173	1.33	5,552.6
2	118.8	1,680.4	51.44	13,979	1.40	5,990.3
3	130.2	1,698.3	59.53	16,163	1.53	6,317.3
4	125.6	1,420.9	77.06	16,962	1.74	6,078.2
1975	115.8	1,286.2	64.53	15,171	2.01	5,957.5
6	112.8	1,422.7	64.62	14,307	2.20	6,390.8
7	105.5	1,411.0	66.72	15,341	2.32	6,727.5
8	121.0	1,408.9	66.53	18.161	2.09	6,879.0
9	127.0	1,411.5	92.75	18,008	2.71	6,757.1
1980	109.2	1,121.9	102.19	15,445	3.41	6,242.4
1	123.1	1,416.5	85.12	16,081	3.43	5,840.2

APPENDIX F

U.S. MOLYBDENUM DATA (YEARLY)

	Total Net Sales of Aerospace Vehicles (millions of dollars)	Stainless Steel Production (thousands of tons)	Total New Construction (millions of dollars)	Total New Orders for Machine Tools-Metal Cutting Type Tools (millions of dollars)
1955	8,470	1,222	46,519	927.10
6	9,496	1,256	47,601	923.50
7	11,766	1,047	49,139	553.15
8	11,470	896	50,047	299.50
9	11,255	1,131	55,392	541.80
1960	10.997	1,004	54,738	535.30
1	14,948	1,137	56,445	591.80
2	15,972	1,085	60,205	572.10
3	16,407	1,204	64,812	759.75
4	16,686	1,443	67,675	1,039.15
1965	17,016	1,493	73,747	1,251.70
6	20,227	1,651	76,414	1,629.90
7	23,444	1,451	78,082	1,134.95
8	25,592	1,432	87,093	1,079.35
9	24,648	1,569	93,917	1,195.30
1970	24,752	1,279	94,855	651.30
1	21,679	1,263	109,950	608.75
2	21,499	1,564	124,085	1,008.95
3	24,305	1,889	157,917	1,825.45
4	26,849	2,150	138,501	2,017.05
1975	29,473	1,111	134,535	915.90
6	31,328	1,684	151,054	1,662.15
7	33,315	1,862	173,975	2,202.05
8	37,968	1,954	205,457	3,373.45
9	46,173	2,107	230,781	4,495.10
1980	57,605	1,701	230,273	3,884.75
1	77,559*	1,770	236,725	2,228.10

*The 1981 value is estimated.