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BASE AND PRECIOUS METALS EXPLORATION BY MAJOR CORPORATIONS

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FOREWORD

In December of 1983, the Mineral Trade and Markets Project sponsored a task force meeting on the Economics of Mineral Exploration in an effort to add to the limited literature available on this topic. The eleven papers prepared for this meeting focus on two important questions: First, what are the important factors influencing the overall level of exploration, as well as its allocation by geographic area and mineral target type? How important are mineral prices, political risk, new developments in exploration techniques, and other factors in this regard? Second, has the productivity of exploration been declining over time? Has it become more difficult and costly to find new mineral reserves because the easier to find deposits generally are discovered first? The papers are now being revised, and will eventually be submitted in an edited volume for publication.

An earlier version of this study on the economics of Base and Precious Metals Exploration by Major Corporations was among the papers presented at the task force meeting. It was prepared by Roderick G. Eggert, a Research Scholar at IIASA with an M.S. in Geochemistry and a Ph.D. in Mineral Economics from the Pennsylvania State University, and draws on research conducted for his doctoral dissertation.

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ABSTRACT

Major private corporations are among the principal actors in the world of mineral exploration. This study analyzes changes in the level and distribution of base and precious metals exploration by a number of large North American and European firms over the last twenty years.

It finds that corporate exploration, like other forms of investment, responds to an interplay of economic, political, and technical factors influencing the expected revenues, costs, and risks associated with this activity. The level of exploration expenditure varies to a large degree with changes in overall expected returns, which are strongly influenced by changing mineral prices, discovery rates, and corporate goals such as diversification. The distribution of funds with respect to both commodities and countries tends to vary with changes in relative potential returns. In the first case, relative mineral prices, discovery rates, advances in exploration and production technologies, new exploration models, and corporate goals such as diversification are important determinants of change. In the second case, geologic criteria, particularly recent discoveries in an area, are the most important determinants of change; the importance of government policies and political risks, although not trivial, has been exaggerated.

Accordingly, corporate exploration works together with material substitution and other forms of technologic change to offset the cost-increasing effects of mineral resource depletion.

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I. INTRODUCTION

Exploration is the search for new mineral wealth. It acts in concert with technologic change and other factors to augment mineral supply. Geological mapping, geochemical sampling, geophysical surveys, diamond drilling, and other exploration activities provide information about unknown resources. This information helps identify mineral deposits, thereby generating new mineral reserves. The new reserves provide ore for smelting and refining operations, which in turn provide unfinished metal to fabricators, who fashion products used ultimately by metal consumers. Exploration influences the availability and prices of minerals, the geographic location of mining and processing, and the international flow of minerals among producing and consuming countries.

This study analyzes base and precious metals exploration by one of the important actors in the world of exploration--major corporations. The objective is to identify and assess the factors responsible for changes in the level and distribution of corporate exploration over the last fifteen to twenty years. Section II discusses exploration as an economic activity, providing a conceptual framework for the analysis. Section III looks at levels of exploration expenditure and how they have changed over time for a number of North American and European companies. Section IV examines the distribution of exploration funds among minerals, paying particular attention to porphyry copper, massive sulfide, molybdenum, and gold and silver deposits. Section V analyzes the distribution of funds among countries, and in doing so examines the widely held belief that recent changes in this distribution have been determined largely by government policies and political risks. Finally, Section VI reviews the findings and discusses several of their implications.

II. EXPLORATION AS AN ECONOMIC ACTIVITY

This study treats corporate exploration as an economic activity. As much as geologists might like to conduct exploration at high levels of expenditure purely for the advancement of knowledge or the sake of enjoyment, those who finance exploration view it as an investment. Companies will invest in this activity when expected net returns, discounted appropriately for time and risk, exceed returns from alternative investments, which include other ways of augmenting mineral supply, such as purchasing a known deposit or using new extraction and processing techniques to improve productivity at existing operations. Variations in exploration activity should reflect, therefore, changes in the components of net returns--expected revenues, costs, and risks associated with exploration.

What factors determine these components of net returns? Exploration revenues are the net returns that can be expected from subsequent development and mining of a newly-discovered deposit. They obviously are influenced by anticipated metal prices, output levels, and future demand, as well as development and mining costs, which in turn are affected by a variety of considerations that alter the productivity and prices of these factors of production (for example, mineral taxation and cost of capital). Exploration costs are influenced by similar considerations that affect exploration productivity and prices for exploration goods and services. These considerations include government policies that directly affect exploration, such as land regulations. Three types of risk are distinguished here--political, economic, and geologic. Political risk reflects the variability in returns to exploration due to government actions. Economic risk reflects the variability in returns due to changing commodity prices and costs of extraction and processing. Geologic risk reflects the variability in returns due to the physical nature of ore bodies, and it consists of two parts: variability associated with the probability of any exploration target becoming an ore deposit, and variability in returns during production due to the physical nature of the ore.

In some instances, however, potential returns from exploration may be so difficult to estimate, because of the time and risks involved in discovering a deposit and then bringing it into production, that changes in exploration's level and distribution may be determined to some extent by habit and simple rules of thumb, rather than by changing estimates of potential returns from exploration.

III. LEVELS OF EXPLORATION EXPENDITURE

Figure 1 traces metal exploration expenditures over time for six U.S. firms, four Canadian firms, and two groups of U.S. and European firms. A word of caution is in order: The data are not completely comparable across firms. Data for the U.S. mining company and the U.S. oil company were obtained directly from these unnamed firms and represent actual expenditures by the corporate exploration group within the firm. The other figures are from published sources. Some data represent exploration expenses claimed for tax purposes on income statements, whereas others represent figures that are called exploration expenditures in annual report texts. The aggregate numbers for U.S. and European companies were tabulated by other authors according to their own definitions of exploration.[1]

[1] Data for Phelps Dodge, the U.S. oil company, and the group of European companies do not include uranium expenditures. The other data undoubtedly include sizable uranium expenditures, but it is not possible to exclude these from the totals. Expenditures for oil and gas exploration are excluded in all cases, with the possible exception of Asarco, whose data may include a small oil and gas component since 1980. The data from published sources include any expenditures for iron ore and bauxite, but such expenditures appear to have been relatively small or nonexistent for most firms. The U.S. GNP implicit price index has been used to deflate all expenditures and prices in this study, except where noted otherwise.

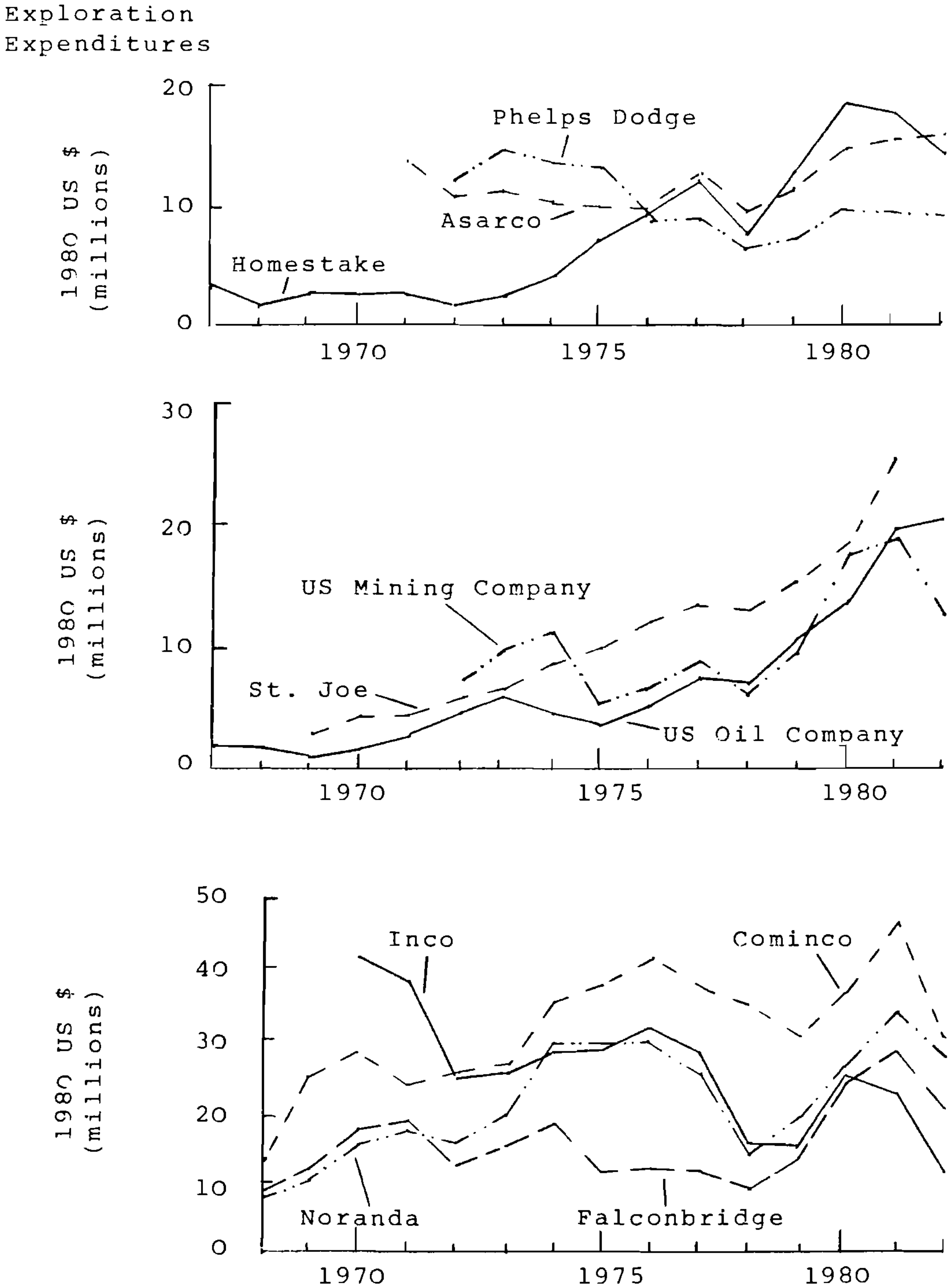


Figure 1. Exploration expenditures for selected North American and European companies (source: annual reports, confidential written surveys). Expenditures have been restated in real terms using the U. S. GNP implicit price index (1980=100).

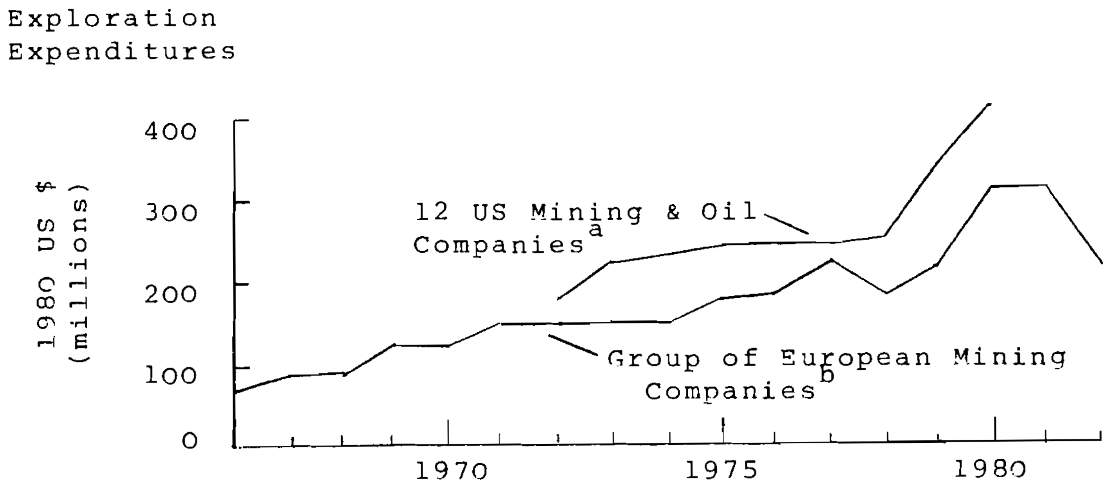


Figure 1 (Continued)

Sources:

[a]Barber (1981)

[b]Crowson (1983)

Despite these inconsistencies across firms, care has been taken to ensure that the data are as consistent as possible over time, thereby permitting analysis of exploration levels over time.

Taken as a group, the curves display several common features. First, the general trend of real expenditures over time is upward (expressed in constant 1980 U.S. dollars). This is particularly true for the group of U.S. and European firms, and most of the individual U.S. companies. The upward trend is less pronounced for the Canadian firms. Second, expenditures tend to be cyclical. This is particularly true for the Canadian companies, along with several U.S. firms. To a lesser extent, European expenditures have also been cyclical over time. Based on the data from this limited sample of major corporations, three recent boom and bust periods for corporate exploration can be identified, although not all firms exhibit all three periods.

The first boom occurred in the early 1970s, most noticeably for the Canadian firms. Subsequent expenditures by the Canadians dropped sharply, while expenditures by the European companies leveled off after a period of steadily increasing expenditures. The second boom occurred in the middle 1970s--for three of four Canadian firms the peak year was 1976, whereas for five of the six U.S. firms and the European group the peak was in 1977. 1978 and, to a lesser extent, 1979 were trough years. The third boom occurred in 1980 and 1981, followed by dramatic expenditure cutbacks in 1982.

Despite these broad similarities, there are pronounced differences among firms. For example, expenditures by some firms change only gradually from year to year, whereas expenditures by others swing sharply over the short term. Expenditures by several firms have followed a generally downward trend, at the same time that the overall corporate trend has been upward. The factors that account for these similarities and differences among firms are considered below.

Mineral prices may be one factor responsible for much of the similarity among company expenditure trends. As will be discussed later in greater detail, mineral prices may be an important driving force behind corporate exploration expenditures by altering expected returns from exploration in two very different ways. First, they may strongly influence expected revenues from exploration. Mineral prices are likely to be an important determinant of expected future prices and thus revenues from mining, which in turn are an important determinant of potential revenues and returns from exploration. Second, mineral prices may strongly influence exploration costs. They are an important determinant of mining revenues and levels of internal funds available for investment; if the cost of external funds is greater than the cost of the limited amount of internal funds, then mineral prices may be responsible for changes in exploration costs.

Figure 2 displays price trends for several major metals that have been important exploration targets in recent years. By comparing real mineral prices (Figure 2) with real corporate exploration expenditures (Figure 1) over time, several qualitative inferences can be drawn. First, the general upward trend in expenditures, identified earlier, corresponds closely with the rise in gold and silver prices. Second, many of the fluctuations in expenditures correspond with price fluctuations. For exam-

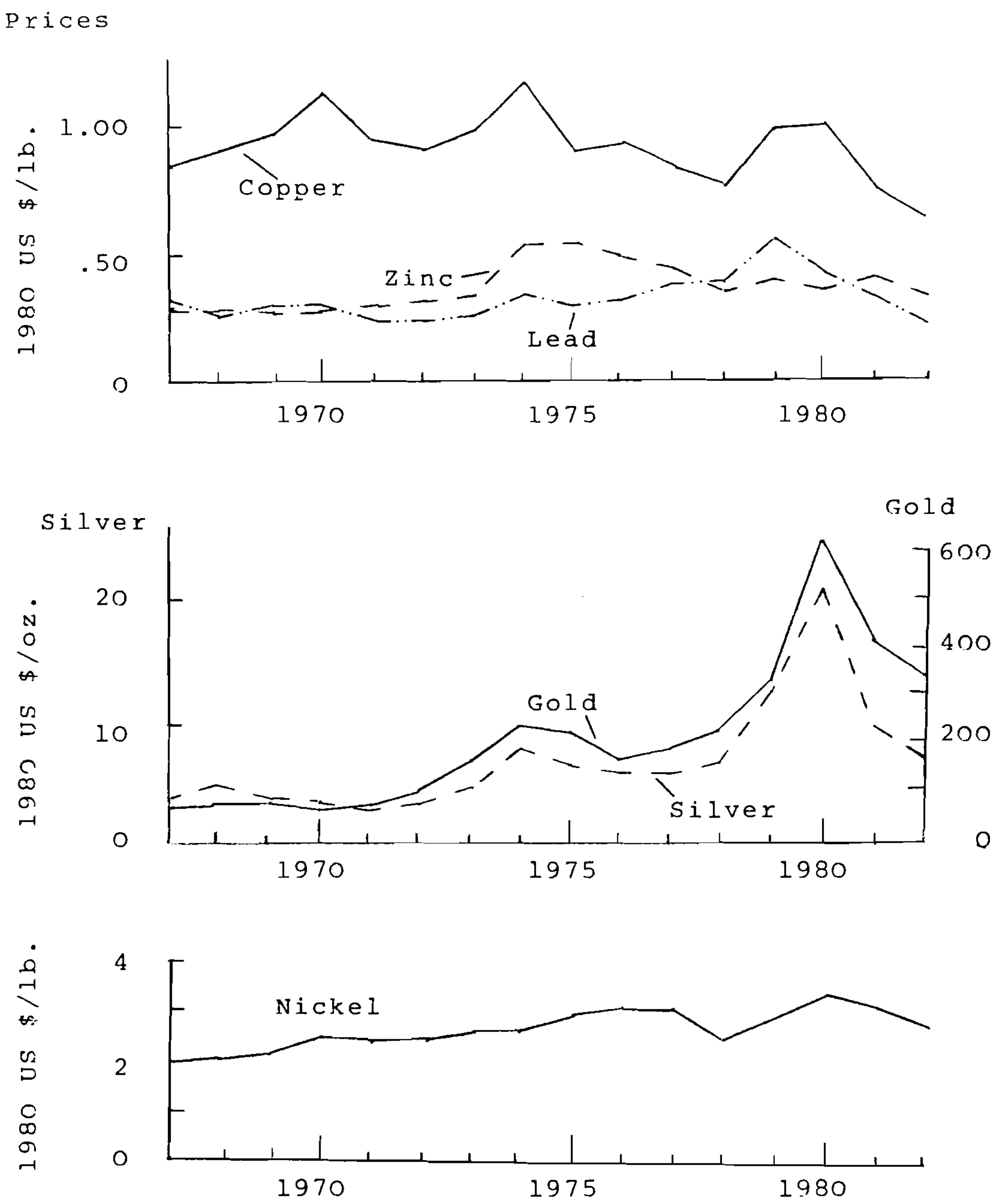


Figure 2. Annual average prices for selected minerals

Sources: Engineering and Mining Journal (1983), Metal Bulletin (1983), Metal Bulletin Books Ltd. (1983), Metallgesellschaft Aktiengesellschaft (1982), and Roskill Information Services Ltd. (1982).

ple, expenditures by the Canadian and several U.S. companies peaked and then fell in the early 1970s, following most mineral price trends with an approximate lag of one year. Copper prices peaked in 1970 and fell sharply in 1971 and 1972, and lead, nickel, and silver prices also fell somewhat in 1971. Inco and Cominco expenditures peaked in 1970; Falconbridge, Noranda, and Homestake expenditures peaked in 1971 and declined in 1972, as did Asarco's.

The next price boom climaxed in 1974 for gold, silver, copper, lead, and zinc. Expenditures by most firms rose during the mid-1970s. For three of four Canadian companies, the surge in expenditures lasted until 1976. For five of six U.S. companies, expenditures increased substantially from 1975 to 1977. Likewise, expenditures by European firms rose from 1974 to 1977.

In 1978, real exploration expenditures fell almost without exception. By this time, zinc and silver prices had been falling steadily since 1974; copper prices had declined by almost one-third compared with the 1974 average (despite a small increase in 1976); and gold prices had fallen during 1975 and 1976, recovering only slightly in 1977.

Prices increased sharply in 1979 and 1980 for gold, silver, copper, and nickel (also for molybdenum, which is not shown on Figure 2). Almost without exception, corporate exploration expenditures rose sharply in these years. Although most prices declined markedly in 1981, most expenditures remained at high levels. It was not until 1982 that expenditures fell, as many mineral prices continued to decline.

This qualitative analysis suggests a very rough relationship between corporate exploration expenditures and lagged mineral prices. When the relationship is tested more rigorously by regressing real expenditures against an eight-mineral price index, lagged one year, the results (Table 1) provide some statistical support for the contention that exploration expenditures are related to mineral prices. In nine of twelve simple linear regressions, the coefficient for lagged mineral prices is positive and significant at the 95 percent confidence level, using a one-tail t-statistic to test for significance. The mineral price index, described further in the Appendix, reflects percentage changes in real prices for the six minerals displayed in Figure 2, as well as molybdenum and tin. These eight metals were selected because they represent the most important base and precious metals in terms of value of mine production.

As introduced earlier, mineral prices may be an important determinant of exploration expenditures for two very different reasons. In the first case, it is argued that mineral prices strongly influence expected revenues from exploration. They are an important determinant of expected future prices and revenues from mining, which strongly affect expected revenues and returns from exploration. Although a number of factors influence estimates of potential returns from future exploration and mining, including expected costs, demand, and other factors discussed in Section II, it is only argued here that recent prices may be a very important determinant of such estimates. Many of the available price forecasting techniques depend on recent price trends; other techniques may implicitly assume a correlation or other type of relationship between

Table 1

Regression Results: Exploration Expenditures Related to a Mineral Price Index Lagged One Year

	Constant	Coefficient for lagged Price Index	n	R^2
Asarco (1971-1982)	5.95* (2.18)	.035** (.012)	11	.57
Homestake (1968-1982)	-7.14* (2.69)	.099** (.016)	14	.85
Phelps Dodge (1972-1982)	3.46 (5.79)	.025 (.021)	10	.59
St. Joe (1969-1981)	14.13 (8.83)	.051* (.024)	12	.90
U.S. Mining Co. (1972-1982)	-1.21 (5.70)	.067* (.031)	10	.49
U.S. Oil Co. (1968-1982)	27.77 (15.25)	.021 (.023)	14	.88
Cominco (1968-1982)	17.43** (5.24)	.098** (.031)	14	.59
Falconbridge (1968-1982)	4.56 (6.14)	.073* (.035)	14	.47
Inco (1970-1982)	-18.89 (17.78)	.127* (.061)	12	.49
Noranda (1968-1982)	7.67 (6.11)	.096** (.035)	14	.68
12 U.S. Firms (1972-1980)	424.56 (230.02)	.527 (.521)	8	.75
European Firms (1968-1982)	43.32 (30.80)	.954** (.183)	14	.79

Table 1 (continued)

Notes:

n = number of observations.

R^2 = coefficient of determination = the percent of the variation in exploration expenditures that can be explained by variations in the price index (lagged one year).

* = significant at the 95 percent confidence level.

** = significant at the 99 percent confidence level (a one-tail t-statistic was used to test for significance because the coefficient is expected to be positive).

Standard errors are displayed in parentheses.

The method of Cochrane-Orcutt was used to correct for first-order autocorrelation. Checks were done with the Hildreth-Lu method to ensure that local solutions for rho had not been found.

recent and future price trends, and they generally assume that the underlying behavioral relationships governing price determination are maintained over time. Changes in exploration expenditures are likely to follow price changes with a short lag, because expenditures in any particular year are the result of a budgeting process that begins at least six months prior to the beginning of that year. Changes in budget allocations and expenditures for exploration in any year, therefore, are likely to reflect changing price expectations and to a lesser extent prices from the previous year.

The second reason exploration expenditures may be related to mineral prices is that mineral prices strongly influence exploration costs for some firms, because of their effect on mining income and the availability of internal funds for investment.[2] This would occur when the cost of external funds (debt or equity) is greater than the cost of internal funds, as shown in Figure 3. SS_1 is a supply curve for investment funds, and the cost of using the limited amount of internal funds is approximately constant. As a firm calls on external sources of debt and equity for additional financing, however, costs increase as the firm's debt/equity ratio increases, or as additional stocks dilute management's control over the firm (see Branson, 1979, pp. 219-220). *DD* is a demand curve for exploration funds. During periods of low prices and correspondingly low levels of internal funds, the equilibrium exploration expenditure corresponds to q_1. During periods of higher prices and

[2]The relationship between exploration expenditures and the availability of internal funds was suggested by Ventura (1982, pp. 12-13), based on graphical similarities between exploration expenditures for some companies and corporate cash flow, lagged one year.

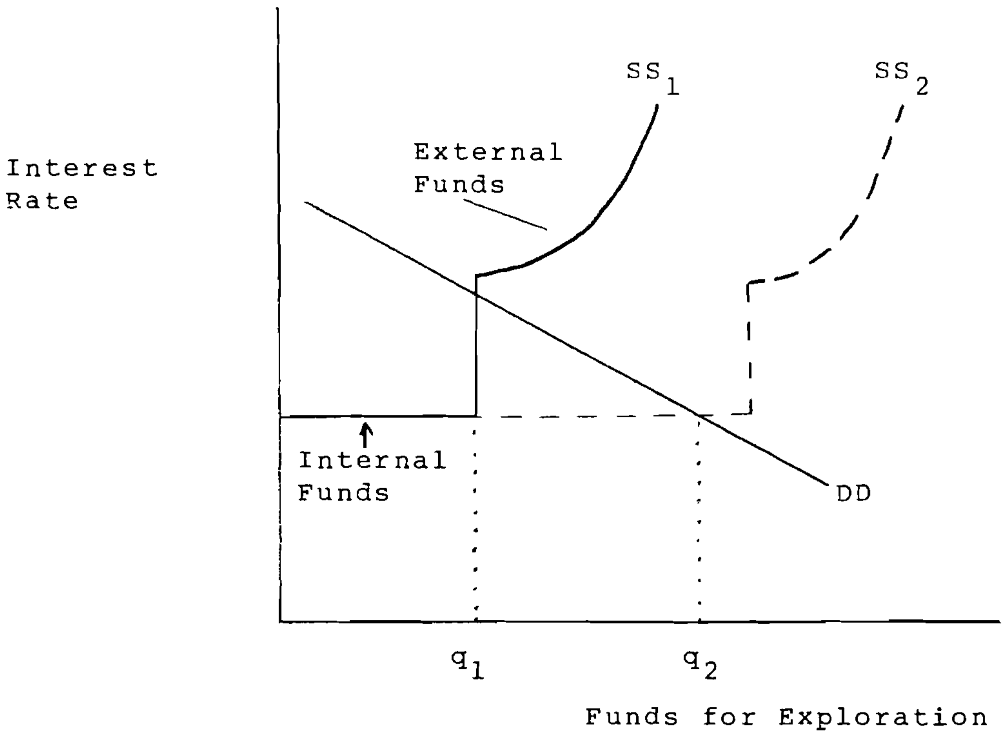


Figure 3. Possible supply and demand schedules for exploration funds

correspondingly higher levels of internal funds, the supply schedule shifts to the right, as depicted by SS_2; in this case, expenditures increase to q_2, even though the demand curve for exploration funds has remained stationary. (Note that in the first argument concerning the relationship between mineral prices and exploration expenditures, mineral price changes cause a shift in the demand curve for exploration funds by altering expected exploration revenues.) Furthermore, corporate exploration involves a great deal of rivalry among competing exploration groups, and companies may be reluctant to call on external sources of finance, if it means divulging information about the exploration program that they would prefer to keep confidential.

For five companies in this study, exploration expenditures correspond closely with net income, which is used to measure the availability of internal funds. The graphs in Figure 4 imply a lagged relationship between expenditures and net income, and this qualitative inference is reinforced by the regression results (displayed in the figure) in the form of positive and significant coefficients for the independent variable, net income lagged one year.

Therefore, mineral prices appear to influence exploration expenditures in two very different ways--by influencing potential revenues and thus the demand for exploration funds, and by altering costs (through their effect on levels of internal funds) and thus the supply of exploration funds. Although both reasons contribute to the similarities among company expenditure trends, the second reason also helps explain the differences among company trends, because not all mineral prices move

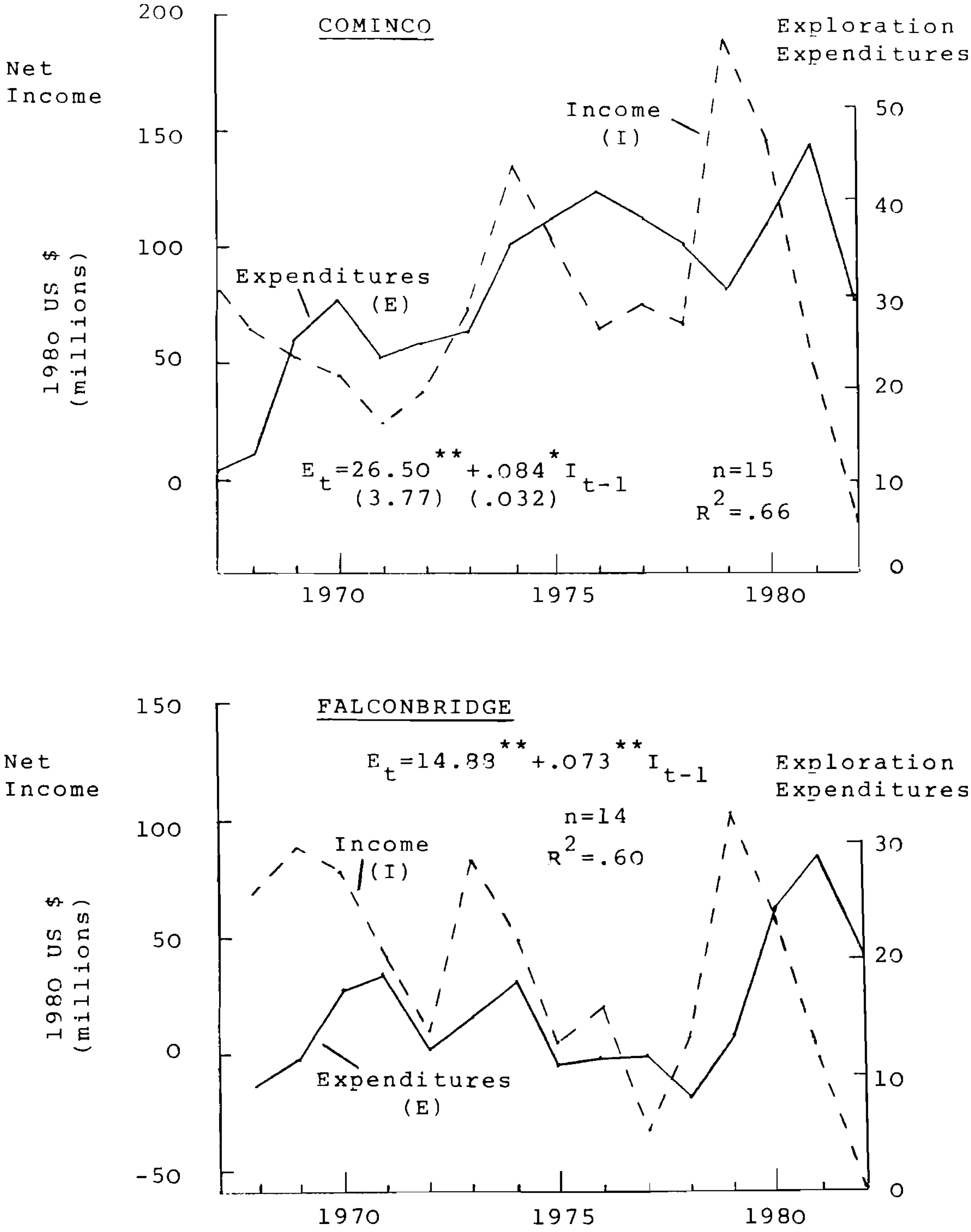
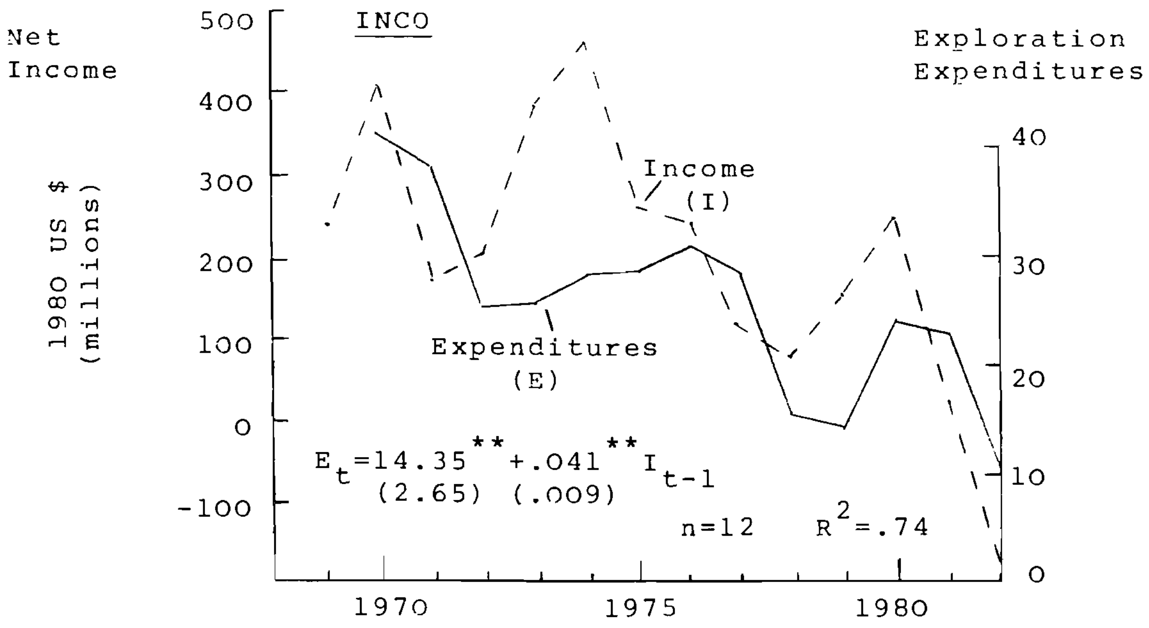
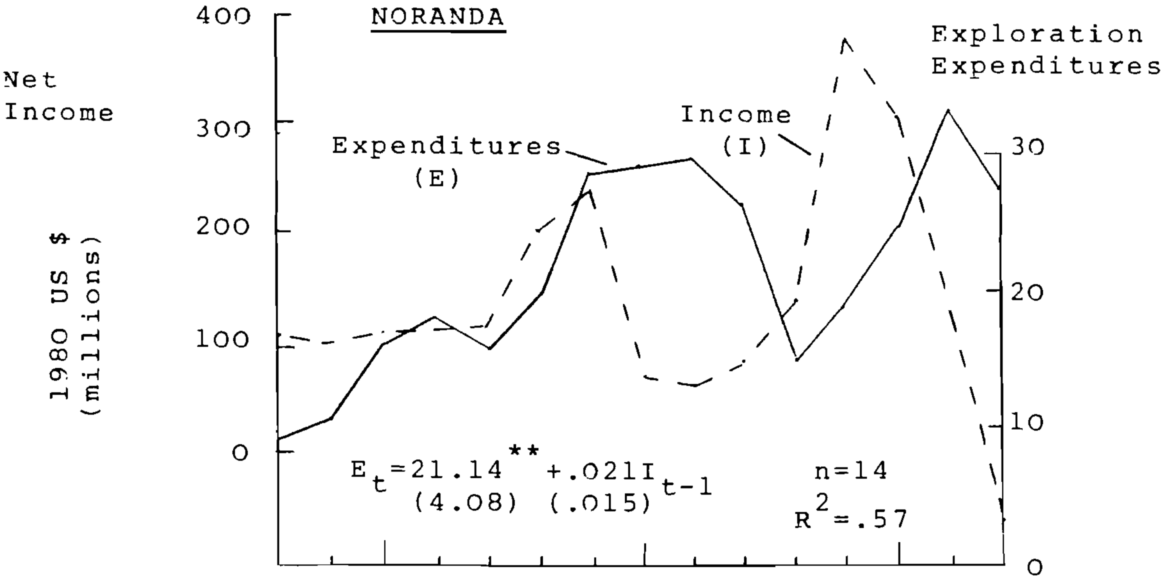


Figure 4. Exploration expenditures and net income over time for five mining companies





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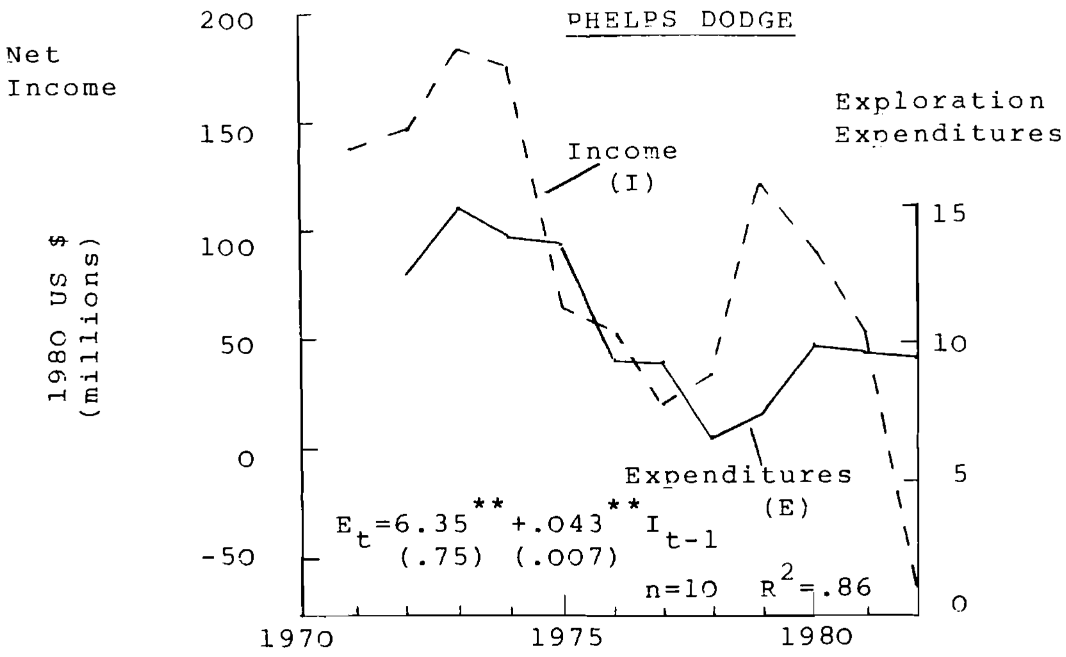

Figure 4 (Continued)

together and not all companies produce the same minerals. Nevertheless, mineral prices alone do not account for all similarities and differences among firms.

The *level of exploration success* is perhaps the most important nonprice factor that influences overall levels of expenditure by a company. A period of successful exploration, when one or several mineral occurrences are discovered, increases expected future returns to exploration, and a firm is likely to increase subsequent expenditures for two reasons. First, when a company discovers promising mineralization during reconnaissance or initial drilling, it is provided with a strong incentive to undertake a detailed drilling and evaluation program on the prospect. This detailed program is usually more expensive than reconnaissance exploration, and the result is an increase in total expenditures for the company. Second, after a company discovers or confirms promising mineralization on one or several prospects, it may very well raise its estimates of potential returns from exploration in general and in response raise budget allocations and overall expenditures for exploration. A period of successful exploration enhances the bargaining position of the exploration manager when it comes to competing within the corporation for investment funds.

In both cases, a company lowers its estimates of geologic risk, which reflects the probability of any prospect becoming a mine. At the same time, a firm may also raise its estimates of potential revenues from exploration and mining. The result is an increase in potential returns from exploration, and the company increases subsequent expenditures. During 1981 and 1982, for example, Asarco spent approximately $7 million (in current terms) on underground exploration on a promising gold prospect discovered in 1980 near Timmins, Ontario, Canada; these expenditures account for much of the increase in Asarco expenditures during these years. At St. Joe, detailed evaluation at two discoveries, El Indio (Chile) and Pierrepont (New York), may be partly responsible for the increase in St.Joe expenditures from 1979 to 1981. Furthermore, a steady stream of St. Joe discoveries throughout the 1970s, including the Woodlawn massive sulphide deposit in Australia, the El Pachon porphyry copper deposit in Argentina, diamonds and tin in Brazil, gold in California, and zinc in Tennessee, may account for the steady rise in expenditures during the period.

Lack of success, on the other hand, may cause a company to lower estimates of expected returns and thus expenditures for exploration. At Phelps Dodge, for example, no significant discoveries were listed in annual reports between 1973 and 1978, and during this period real exploration expenditures declined. In 1978 Phelps Dodge announced the discovery of porphyry molybdenum mineralization near Pine Grove, Utah, and expenditures increased during 1979 and 1980, coinciding with detailed evaluation of this target.

A second important nonprice factor that influences overall levels of exploration expenditures is a change in *corporate goals* or philosophy. A decision to diversify production among a number of commodities is one such change. By successfully diversifying, a company lowers its exposure to overall risk and increases the present value of its activities. If a company believes the best path to diversification is through exploration and discovery of new mineral deposits, rather than through acquisition of known deposits, then it may reasonably decide to increase exploration expenditures. At St. Joe, for instance, annual report statements suggest that efforts to diversify production away from lead have been partly responsible for increased exploration expenditures during the 1970s. At the U.S. oil company, the general rise in expenditures from 1967 to the mid-1970s also reflects, at least in part, a corporate desire for diversification. This company is one of a number of U.S. oil companies that have become increasingly active in nonfuel mineral exploration over the last ten to twenty years. Realizing that diversification into minerals production through exploration would take a number of years, this company was prepared to increase funding gradually for a few years, even if no immediate discoveries were made.

IV. EXPLORATION TARGETS

A second major exploration decision that a firm must make, in conjunction with how much to spend on exploration, is what to explore for. This section examines how the allocation of funds has changed over time for porphyry copper, massive sulfide, molybdenum, and gold and silver deposits and identifies several factors that have been responsible for these changes. It then generalizes and describes a typical cycle in the exploration for any particular deposit-type. The section closes with a discussion of the phenomenon of diversification that has characterized many exploration programs in recent years.

Data from two unnamed companies, who provided historical breakdowns of their exploration expenditures according to commodity or deposit-type, form the quantitative basis of this section. For gold and silver, data are available from five companies. The quantitative information is evaluated in light of additional evidence available from published sources about other companies.

This section looks at the role of changing relative prices in this allocation of exploration funds, and a word is in order about how relative mineral prices have been defined and calculated in this study. The relative price for a mineral reflects how the mineral's price has changed relative to other major mineral prices. In any given year, it has been calculated by dividing the mineral's price by the mineral price index introduced in the previous section.

Porphyry Copper

Porphyry copper deposits are estimated to contain 40 to 45 percent of world copper reserves (Gluschke, Shaw, and Varon, 1979, p. 45) and have been important targets for many exploration groups over the last twenty-five years. As shown in Figure 5, porphyry copper's share of overall exploration expenditures has declined markedly for both firms over the period 1972-1982. Porphyry copper's share for the industry as a whole probably followed a similar declining trend, based on anecdotal remarks in trade journals and elsewhere (for example, Tremblay and Descarreaux, 1978, p. 94; and Hodge and Oldham, 1979, p. 97).

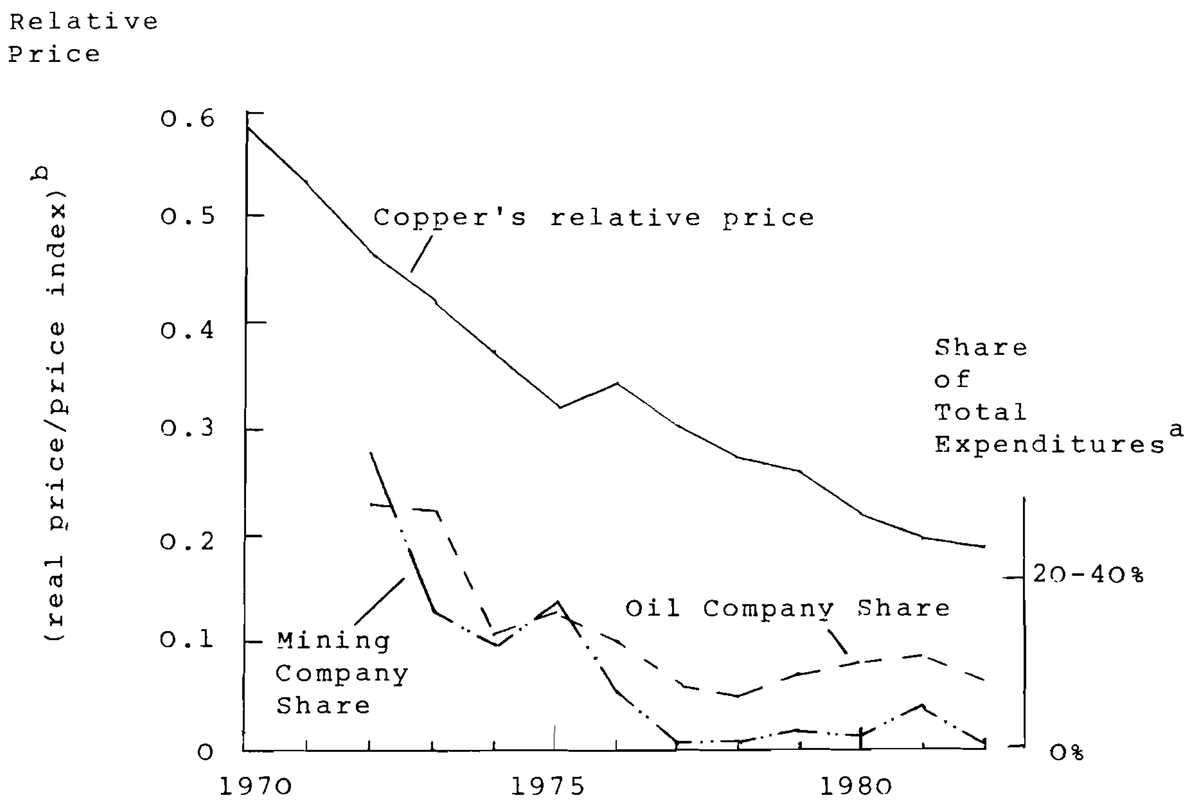

Figure 5. Porphyry copper's share of total exploration expenditures for two firms, and copper's relative price.

[a] To protect the identities of the two firms, only a range of percentages is provided in the figure.

[b] See the Appendix for details about the price index.

The decline in copper's real price relative to the eight-mineral price index has roughly paralleled porphyry copper's decline in share of expenditures. One might reasonably infer that copper's declining relative price has been partly responsible for the fall in porphyry copper's share: as copper's price has fallen relative to other major metal prices, estimates of future prices and potential revenues have declined and copper has become relatively less attractive as an exploration target.

Nevertheless, porphyry copper's changing share of expenditures has not completely followed changes in copper's relative price. In particular, porphyry copper exploration increased in importance during the period 1978-1981, while the relative price of copper fell. This probably is due in part to rising relative prices for three metals commonly associated with porphyry copper deposits--gold and silver, whose relative prices rose dramatically from 1977 to 1980, and molybdenum, whose relative price increased sharply from 1977 to 1979. As prices for the associated minerals rose, expected future prices presumably also rose. This, in turn, increased potential revenues from deposits containing the associated minerals, resulting in an increase in the relative importance of porphyry copper exploration. As an example, in 1979 the oil company initiated a substantial porphyry copper exploration program in South America, at a time when relative molybdenum, gold, and silver prices were increasing. Since then, relative prices for all three associated minerals have fallen substantially, and the relative importance of porphyry copper deposits has declined for both exploration groups.

In addition to falling relative mineral prices, three other factors may have been responsible for porphyry copper's declining share of expenditures. First, porphyry copper deposits were important exploration targets from the mid-1950s to the mid-1970s, and many discoveries were made, greatly expanding copper reserves. A number of known porphyries are waiting to be brought into production. Accordingly, the possibility has declined for discovering lower-cost porphyry deposits than this existing stock of porphyries, in the absence of new ore deposit concepts or advances in production technologies. Second, capital and energy costs for large, low-grade porphyries may have risen more rapidly than similar costs for smaller and higher-grade metal deposits; real costs have increased as newly-discovered porphyries have declined in grade, been farther below the surface, and located in more remote areas (see United Nations, 1981, p. 17). Third, multimetallic deposits, such as massive sulfides, appear to have gained in importance in many exploration programs because significant production of several metals can occur simultaneously. Companies have been attracted by the potential for significantly diversified production from one deposit, reducing fluctuations in earnings caused by price instability.

Massive Sulfides

Massive sulfide deposits, generally higher-grade and smaller than porphyry copper deposits, typically contain significant concentrations of copper, lead, and zinc and have received considerable attention from explorationists over the last twenty years. As shown in Figure 6, massive

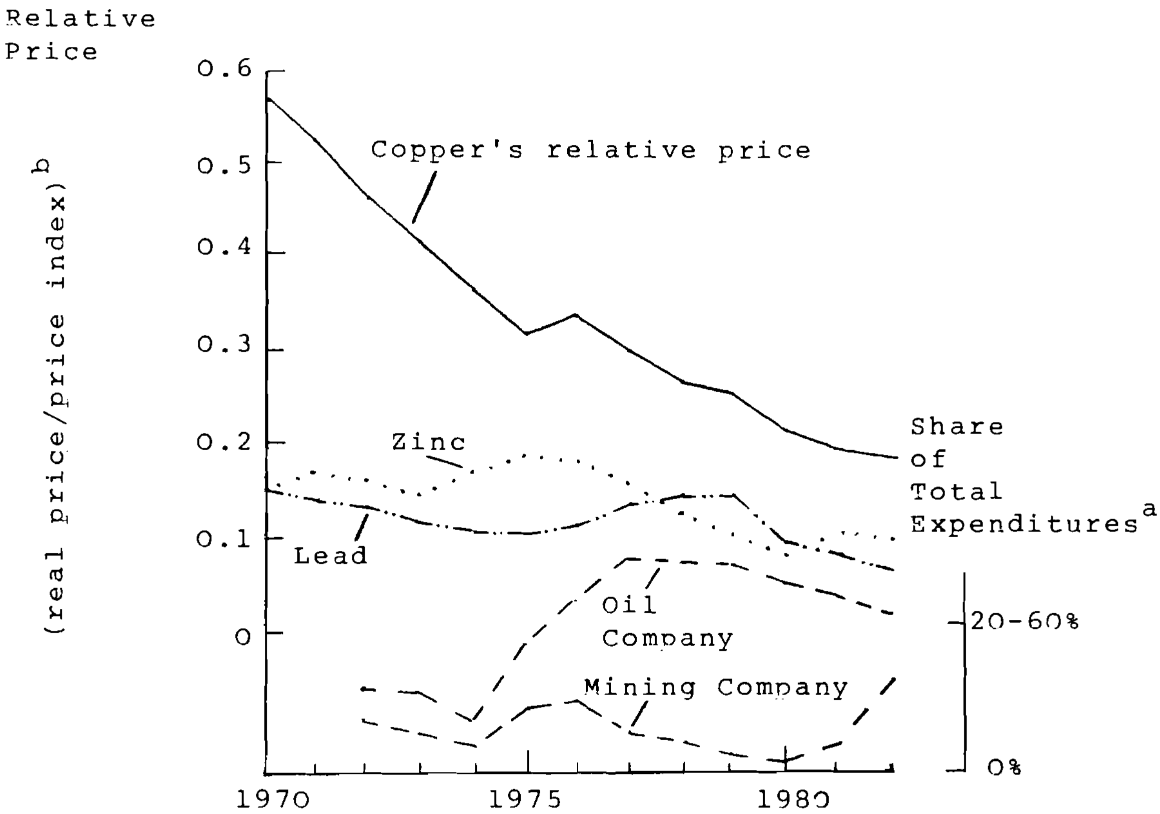

Figure 6. Massive sulfide's share of total exploration expenditures for two firms, and relative prices for copper, lead, and zinc.

[a] To protect the identities of the two firms, only a range of percentages is provided in the figure.

[b] See the Appendix for details about the price index.

sulfide's share of total expenditures for both firms declined moderately through 1974 and rose abruptly in 1975 and 1976. This increase in share for both companies appears to conform to an industry-wide surge in massive sulfide exploration. As noted by Mullins, Lawrence, and Deschamps (1977, p. 105), "while porphyry copper lost its glamour, massive sulfides became a favorite of explorationists." Since then, however, massive sulfide shares have followed significantly different paths for these firms. For the oil company, massive sulfide exploration has grown to be a very important part of its program. For the mining company, massive sulfide's share declined so that by 1980 it represented a very minor component of its overall program; by 1982, however, the share had grown to its highest level for the 11-year period. It is unlikely that relative mineral prices have been the major driving force behind the sharp changes in massive sulfide's share of expenditures. During this period, copper's relative price fell considerably, whereas relative prices for lead and zinc fluctuated around a generally declining trend.

For the oil company, massive sulfide exploration developed into an important part of the overall exploration program during a period (1975-1977) when relative lead and zinc prices were generally steady or increasing. Since then, massive sulfide's share has declined somewhat, roughly paralleling the decline in relative prices. Nevertheless, the decline has not been greater because of the company's commitment to copper, lead, and zinc exploration. According to the exploration manager, the company remains committed to these commodities because they meet the following criteria: expected demand must be large and growing (or at least level), current production capacity must be insufficient to meet these demands over the next five to twenty years, and deposit-types must be large enough so that production will have a noticeable impact on the oil parent's income statement. The company believes that profits can be made over the next five to twenty years from minerals that satisfy these criteria, as long as deposits are found with low costs relative to current producers. Thus copper, lead, and zinc have been and remain an important part of the oil company's metal exploration efforts despite falling relative prices, because estimates of potential returns from production of these minerals have not diminished significantly.

For the exploration industry as a whole, the apparent increase in massive sulfide's share of overall expenditures during a period when relative prices for copper, lead, and zinc were generally falling may be explained by several factors. First, for reasons discussed earlier, porphyry copper exploration has been so successful that the possibility has declined for discovering lower-cost porphyry deposits than the existing stock of porphyries; massive sulfides, with relatively lower capital and energy costs, have become an alternative target for copper. Second, massive sulfide deposits provide an opportunity for significant production of a variety of minerals, usually copper, lead, and zinc, and often minor amounts of gold, silver, and other minerals. By the mid-1970s many firms appear to have become very concerned about diversification of production among several commodities, as discussed earlier. Third, several significant massive sulfide deposits were discovered in the mid-1970s that created an excitement among explorationists about the possibilities of additional massive sulfide discoveries. The discoveries near

Izok Lake (Northwest Territories, Canada), Timmins (Ontario, Canada), and Crandon (Wisconsin, USA) are but three of many examples. This successful exploration, the flurry of massive sulfide discoveries, undoubtedly increased perceptions of potential returns from similar exploration and resulted in an increase in massive sulfide's share of expenditures in the mid-1970s.

Molybdenum

Molybdenum became an important exploration target for many exploration groups during the 1970s. As shown in Figure 7, molybdenum's share of mining company expenditures grew steadily from 1972 to 1978, remained fairly level through 1980, and has fallen precipitously since then. For the oil company, molybdenum exploration commenced in 1979, grew substantially in importance during the next two years, and fell sharply in importance in 1982. For major corporations as a whole, molybdenum's share may very well have followed a similar path--steadily increasing share in the late 1970s, 1980, and in some instances 1981, followed by a drastic drop in share since then. During the same period, the relative price of molybdenum declined somewhat from 1972 to 1974, increased moderately during the next three years, rose sharply during 1979 and 1980, and has fallen significantly since then.

The factors encouraging increased molybdenum exploration in the late 1970s certainly must include rising relative prices, reflecting rising real prices. The spot price went from $2.90/lb. in 1975 to $9.22/lb. in

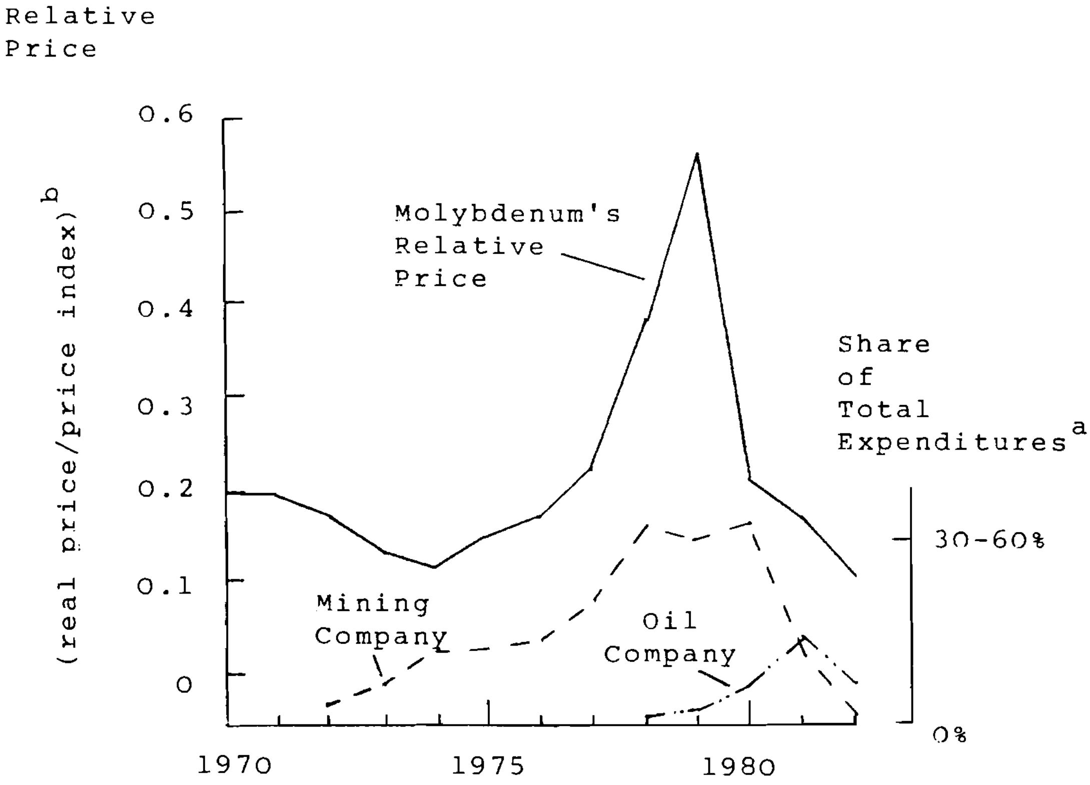

Figure 7. Molybdenum's share of total exploration expenditures for two firms, and molybdenum's relative price.

[a]To protect the identities of the two firms, only a range of percentages is provided in the figure.

[b]See the Appendix for details about the price index.

1979 and $22.00/lb. in 1980; in constant 1980 U.S. dollars, these translate into prices of $4.12, $10.08, and $22.00--an increase of over 500 percent. Another factor, related to molybdenum prices, that encouraged rosy perceptions of potential revenues from molybdenum exploration in the late 1970s was the importance of the metal in many uses relating to energy production, at a time when energy-related exploration was booming. As noted by Distler (1981), molybdenum provides strength and corrosion resistance to a number of alloys that are important in deep oil and gas drilling, enhanced recovery techniques, and Arctic conditions.

The precipitous decline in molybdenum's share of exploration expenditures in the last year or two appears to be largely the result of the current and potentially chronic state of excess mine capacity, created by new mines and recent discoveries. Examples include: Arco-Anaconda's mine near Tonopah, Nevada; U.S. Borax's Quartz Hill deposit in southeastern Alaska; Amoco's Thompson Creek deposit in Idaho; Exxon's Mount Hope deposit in Nevada; Amax's Mt. Emmons (Colorado) and Mt. Tolman (Washington) projects, which have been put on hold; and the Phelps Dodge-Getty Oil deposit near Pine Grove, Utah. This specter of oversupply is reinforced by the potential for significantly more byproduct production of molybdenum from many porphyry copper mines.

Gold and Silver

Gold and silver deposits became important exploration targets for many companies during the 1970s and early 1980s. As shown in Figure 8, gold and silver's share of overall exploration expenditures has risen

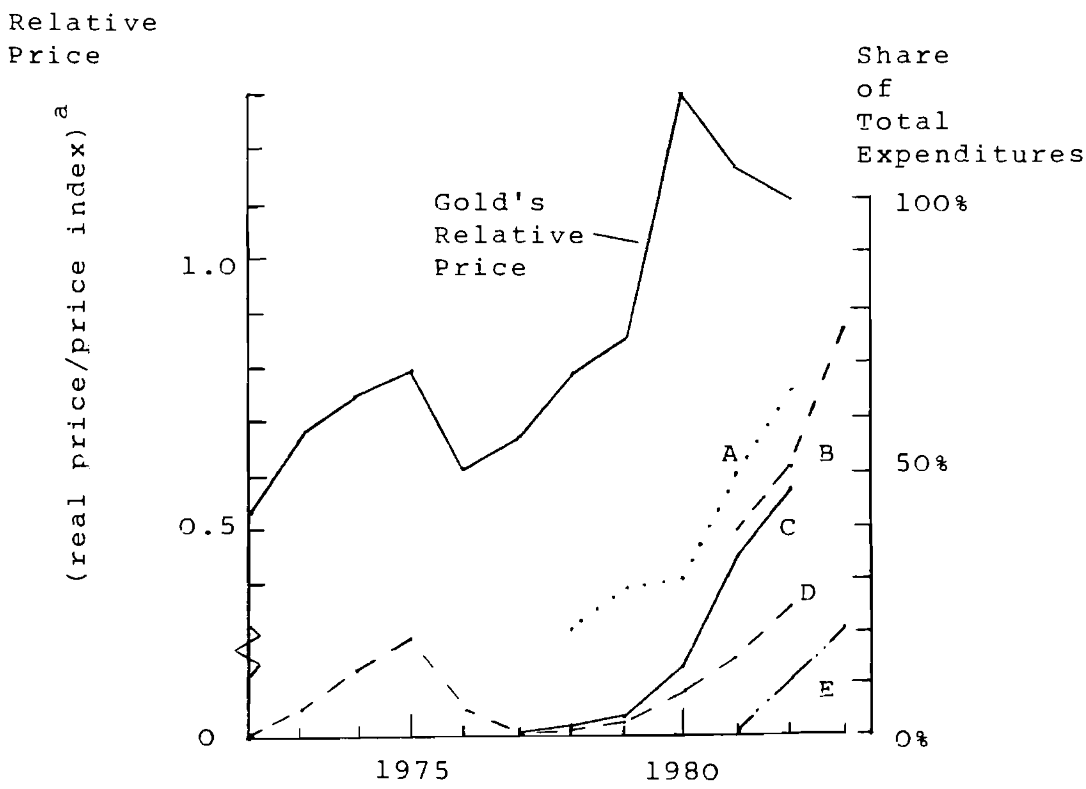

Figure 8. Gold and silver's share of total exploration for five firms. Firms A, B, and C are U.S. mining companies, and Firms D and E are U.S. oil companies. Source of share data: company exploration departments. Share data for 1983 are budget allocations, not actual expenditures.

[a] See the Appendix for details about the price index.

dramatically in the last several years for five companies that provided data directly to the study. Moreover, annual reports for other companies substantiate the trend: For example, Asarco, Homestake, Inco, and Kennecott all report that gold and silver constitute an increasing portion of their exploration expenditures.

Gold and silver prices relative to other major metals have risen dramatically since the early 1970s. Gold's relative price, displayed in Figure 8, experienced short-term highs in 1975 and 1980. Silver's relative price has followed a similar but not identical path. Increased relative prices have undoubtedly had a lot to do with the increased share of exploration expenditures devoted to gold and silver exploration, by creating enormous expectations about potential revenues from future production of these metals. Two other factors, however, appear to have acted in concert with prices to stimulate the recent boom in gold and silver exploration. First, as noted by Brown (1983), recent improvements in heap leaching and carbon-in-pulp recovery of gold permit profitable production from the low-grade ores that are typical of many recent discoveries. Second, in a more limited sense the desire to diversify production among a number of minerals seems to have contributed to the growing importance of precious metals exploration. St. Joe and Inco, for example, initiated sizable gold and silver exploration efforts as part of diversification programs.

Finally, data from company D in Figure 8 show how the interplay of prices and exploration success can influence a particular mineral's share of overall exploration expenditures. Gold and silver's share climbed from zero percent in 1972 to almost 20 percent in 1975, only to decline sharply in 1976. According to this company's exploration manager, the initial interest in gold and silver exploration was primarily due to rising prices in the early 1970s. The subsequent share increases in 1974 and 1975 were largely due to detailed drilling and evaluation of a promising gold prospect, which was detected during the earlier exploration that was stimulated by rising prices. In 1976, gold and silver's share fell sharply as the detailed evaluation was completed. In response to the drop in gold prices, the deposit was put on hold awaiting higher prices. Little, if any, new gold and silver exploration was initiated until 1980 when the company responded to the relative price increases of the previous three years.

The Episodic Nature of Exploration and Discovery

It appears that exploration and then discovery of particular minerals follow episodic or cyclical patterns over time. The following discussion generalizes from the previous analysis in this paper and draws on work by Rose and Eggert (1983), which presents more detailed information on the discovery of specific minerals.

The idealized cycle begins with incentives for stepped up exploration for particular minerals. Initial incentives take a number of forms, including: 1) increased mineral prices and demand, which raise estimates of potential revenues from future production, 2) new or revised geologic models,[3] and 3) improved exploration and production

[3]A geologic model is an idealized set of geologic characteristics common to most or all depo-

technologies. The final two factors contribute to lower exploration and mining costs, and all three factors contribute to greater profitability than otherwise would occur.

The cycle continues with a flurry of exploration activity, leading to a number of discoveries. The initial discoveries provide added incentives for more exploration over the short-term, for reasons explained earlier in the paper. A bandwagon effect is often apparent: a successful leader or innovator in exploration is followed by a legion of imitators. Over the longer-term, discoveries of a particular mineral or deposit-type discourage further exploration by greatly expanding known sources of supply. This leads to the final stage in the idealized cycle: declining exploration activity and discovery. Falling prices and demand also may contribute to the final stage.

With regard to the minerals discussed earlier in this paper, the following cycles can be identified. Porphyry copper exploration went through a long cycle that lasted from the mid-1950s to the mid-1970s. Steadily growing copper demand and refinement of a geologic model of ore occurrence contributed to the interest in porphyry copper deposits. Discoveries, the leveling off of copper demand, and increases in capital costs for porphyry deposits relative to other deposit-types contributed to the falling interest.

Porphyry molybdenum exploration, on the other hand, experienced a much shorter cycle in the middle and late 1970s. Price increases, as well as optimistic projections of future demand and a geologic model,

sits of a particular type. It is used as a guide for reconnaissance exploration and subsequent follow-up work.

contributed to the boom. Falling prices and a spate of discoveries were primarily responsible for the cycle's end.

Gold and silver are in the midst of an exploration boom. Price increases appear to have been the boom's major determinant, although improvements in processing technology have been a contributing factor, as discussed earlier.

Massive sulfides, in contrast to the other deposit-types looked at in this study, appear to have experienced less pronounced exploration episodes. Nevertheless, there has been a small boom in recent years due mainly to the opportunity for diversified production, lower capital and energy costs relative to porphyry deposits, recent discoveries, and a geologic model of massive sulfide occurrence. In addition, much massive sulfide exploration occurred during the 1950s in Canada following the development of airborne and ground electromagnetic techniques, which permitted assessment of large areas that lack rock exposure at the surface (Cranstone, 1983).

Diversification

An important element of many recent corporate exploration programs has been diversification. Any analysis of how exploration funds have been allocated among commodities, therefore, would be incomplete without some discussion of this phenomenon.

A primary purpose of diversification is to reduce fluctuations in earnings due to price instability. In addition, diversification into several commodities, such as gold and oil and gas, has been driven by price increases that have raised potential financial returns from an investment in these commodities.

Before specifically discussing diversification of exploration programs, it is important to realize that exploration is only one of three alternative means of achieving diversified production. The other options are to acquire a known deposit that then will be developed and brought into production, or to purchase an operating company. Most companies have used a combination of these three methods in their diversification efforts.

The diversification of exploration programs has occurred on at least four different levels. First, a number of companies that prior to the 1970s explored for a limited number of minerals, usually in the vicinity of existing mines for minerals to extend the lives of existing operations, have broadened their programs to explore for a number of minerals in a variety of geographic and geologic conditions. For example, prior to the 1970s St. Joe was primarily a producer of lead and zinc with operations in the United States, and most of their exploration efforts were aimed at expanding the lead-zinc reserves of existing operations. During the 1970s, St. Joe significantly increased exploration expenditures and began to explore for a much wider range of metals. They became a gold producer in Chile in 1979 (a St. Joe discovery) and California in 1980 (a St. Joe acquisition), and an iron ore producer in 1979 with the formation of the Pea Ridge Iron Ore Company. At the same time, St. Joe also made diversification investments in energy resources--they purchased CanDel Oil Ltd. (1973), Massey Coal (1974), Tennessee Consolidated Coal (1976), and Coquina Oil Corp. (1977). Inco is another example of a mining company that historically had a limited exploration focus, nickel, and now has a much broader focus, including gold and oil and gas.

Second, as noted previously, multimetallic exploration targets, such as volcanogenic massive sulfides, have become increasingly important as companies have become more concerned about reducing fluctuations in earnings due to price instability. Multimetallic deposits enable diversification into more than one mineral, but require opening only one mine.

Third, energy minerals, including uranium, coal, and oil and gas, have become increasingly important exploration targets for mining companies. Figure 9 shows how exploration for energy minerals has evolved over time for Amax and Phelps Dodge. Other mining companies to make sizable investments in oil and gas exploration in recent years include Asarco, Homestake, Newmont, Noranda, and as mentioned previously, Inco and St. Joe.

Finally, in perhaps the most well known example of exploration diversification, metals have become important exploration targets for many major oil companies. Some companies, such as Exxon and Getty, entered metals exploration by forming new exploration groups within the company. Other companies, such as Arco, Pennzoil, and Sohio, relied primarily on acquisitions of existing companies to enter metals exploration. Still other companies, such as Amoco, drew heavily on both methods. In many instances, oil companies were initially attracted to metals exploration by the lure of the energy metal, uranium, and subsequently expanded their programs to include other metals; Figure 10

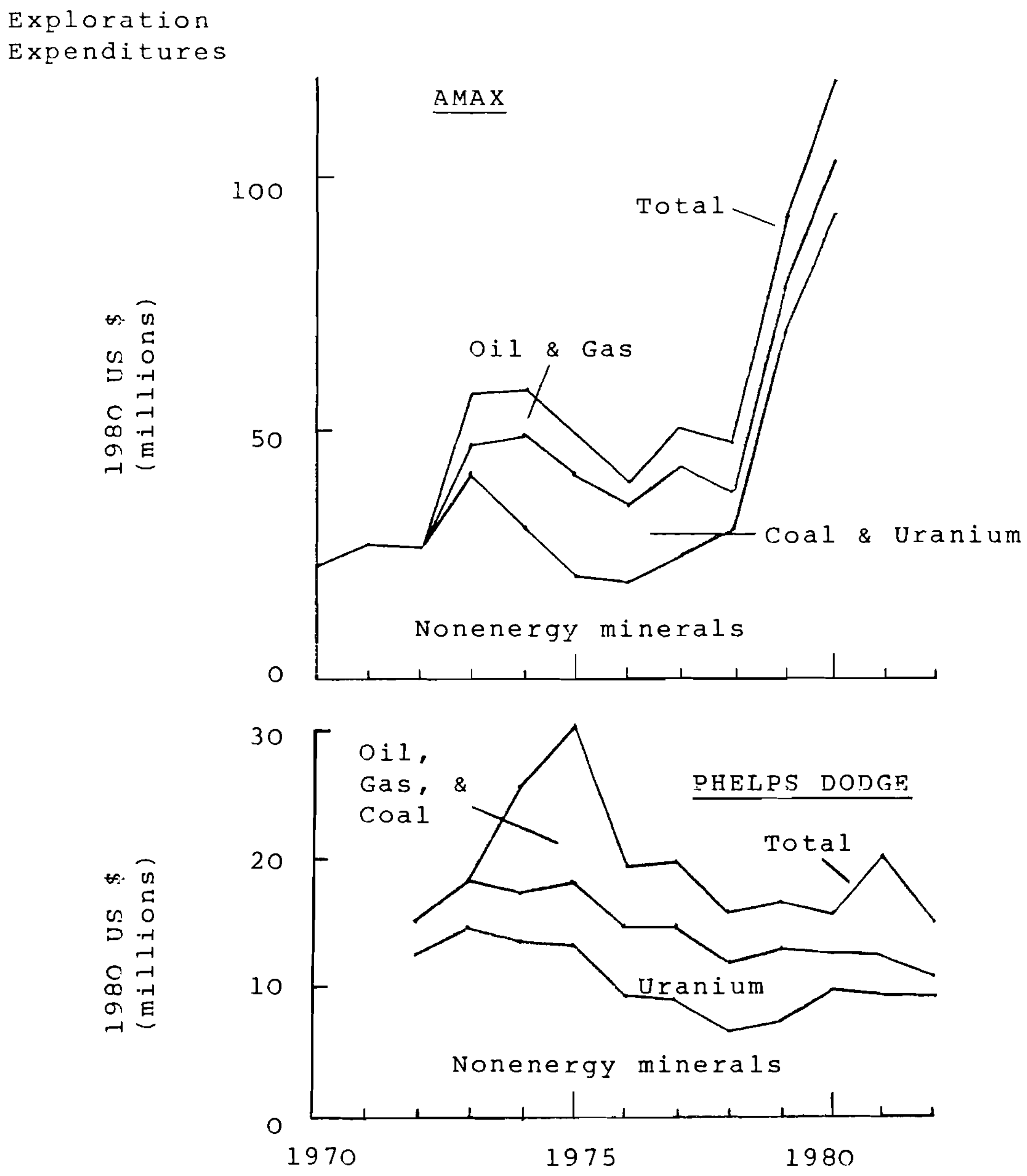

Figure 9. Distribution of exploration expenditures among energy and nonenergy minerals for Amax and Phelps Dodge. Source: annual reports.

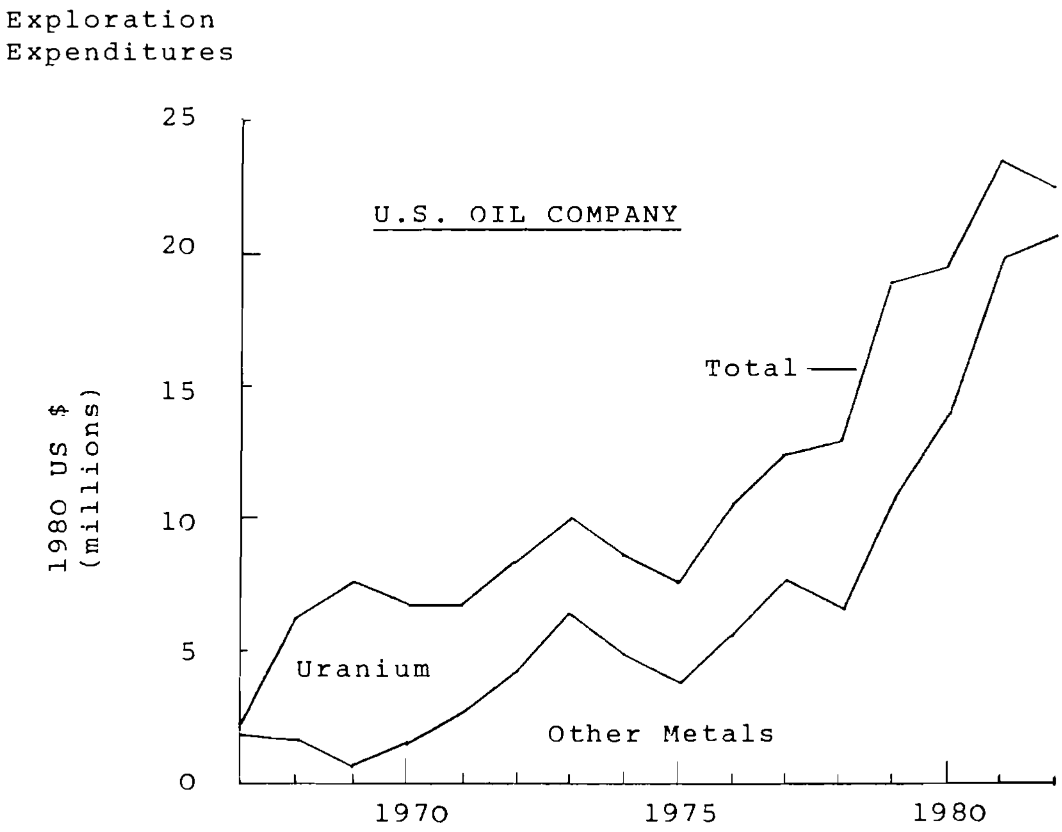

Figure 10. Distribution of metal exploration expenditures between uranium and other metals for a U. S. oil company. Source: oil company exploration department.

displays this pattern for one oil company.

V. LOCATION OF EXPLORATION

A third major exploration decision that a company must make, in conjunction with how much to spend and what to look for, is where to explore. This section examines how the geographic allocation of corporate exploration expenditures has changed over time for Australia, the United States, and developing countries, after reviewing the results of previous research for Canada. It specifically asks the question how important are changing government policies and political risks in determining changing geographic patterns of exploration investment.

Although many factors presumably influence the location of exploration, including geologic potential and availability of infrastructure, it frequently is argued that government policies and political risks are of overriding importance to corporate explorers. For example, changes in Australian and Canadian policies in the 1970s concerning taxation, ownership, and other issues have been blamed for reductions in exploration there. For the United States, Barber (1981, p. 23) suggests that the

> greatest stimulus for expanding foreign exploration by U.S. companies...[is] our federal government. The precipitous withdrawal of our public lands prior to adequate evaluation of their mineral potential has provoked reduction or termination of domestic exploration programs.

In developing countries, increases in political risk are often cited as the primary cause of what has been perceived to be a dramatic decline in recent corporate exploration there. For example, the Brandt Commission report (1980, p. 155) states

> The mining companies place much of the blame [for the shift away from exploration in developing countries] on the instability of concession agreements in the Third World, and the erosion of what they regard as their contractual rights by nationalization.

The rationale is that government policy changes raise or lower the costs and thus the investment attractiveness of operating in a country by providing incentives or disincentives for exploration and mining. Incentives take a number of forms, including tax holidays for new mines, exclusive exploration rights for large blocks of land, and concessionary power rates for mineral processing facilities. Disincentives include host-country ownership requirements, restrictive land and tax policies, and environmental regulations. Political risk, on the other hand, reflects the variability in returns due to government actions. Changes in perceived political risk alter the investment attractiveness of a country by raising or lowering the risk premium that is required by firms to invest in an area and thus influence potential returns there. This section, therefore, examines the extent to which changing government policies and political risks have been the driving forces behind recent changes in the geographic allocation of corporate exploration expenditures.

Canada

DeYoung (1977, 1978) studied the effects of Canadian tax law changes in the early 1970s on mineral exploration there, and his results provide some support to the belief that policies and risks are of considerable importance to the location of exploration. By comparing trends over time in mineral exploration in various Canadian provinces with neighboring regions, he concluded that the major effect of tax changes was to shift the location of exploration from one political region to another.

The most striking example is British Columbia, where exploration expenditures, drilling footage, and claim staking declined in 1974 and 1975, following the introduction of particularly onerous provincial tax changes, including two layers of royalties; at the same time, exploration appears to have increased in the neighboring U.S. states of Alaska, Washington, and Montana, and in the Yukon and Northwest Territories of Canada, which as territories under federal control were not significantly influenced by federal-provincial tax battles (DeYoung, 1978, p. 31). At the international level, DeYoung (1977, p. 102) noted that Canadian mining companies are estimated to have spent 60 percent of their exploration funds abroad in 1975, compared with 20 percent in 1971. Nevertheless, DeYoung admitted that it is clearly impossible to separate the impact of changing tax laws from other factors that affect exploration budget allocations, such as mineral prices and geologic concepts.

Australia

In December 1972 the Labor Party was elected to power in Australia, and as shown in Figure 11, private exploration expenditures declined in real terms over the next three to four years. In December 1975 the Labor Party was defeated, the Liberal-National Party coalition returned to power, and since then exploration expenditures have risen steadily. It has been argued that changes in government policies and the associated uncertainty over potential future policy changes (that is, political risk) are largely responsible for these trends in exploration expenditure. Commenting in 1974 on the Labor government, Derry, Michener, and Booth (1974, p. 48) maintain "that the degree of uncertainty which now hangs over every aspect of mining and exploration in Australia has virtually halted significant exploration and mining development." Three years later Mullins, Lawrence, and Deschamps (1977, p.104) wrote that "Australia is rapidly gaining in stature following the return to power of the Liberal-National Party coalition."

Exploration expenditure data from four sources are used here in conjunction with other information to examine these and other changes in the level of expenditures and the share of overall exploration expenditures devoted to Australia. Although it is difficult to determine how much of any change in expenditures is due to changing government policies and political risks and how much is due to other factors, if expenditure changes represent reactions to changing policies and risks, then one would expect the share of overall expenditures devoted to exploration in a country to increase during periods of favorable policies and low

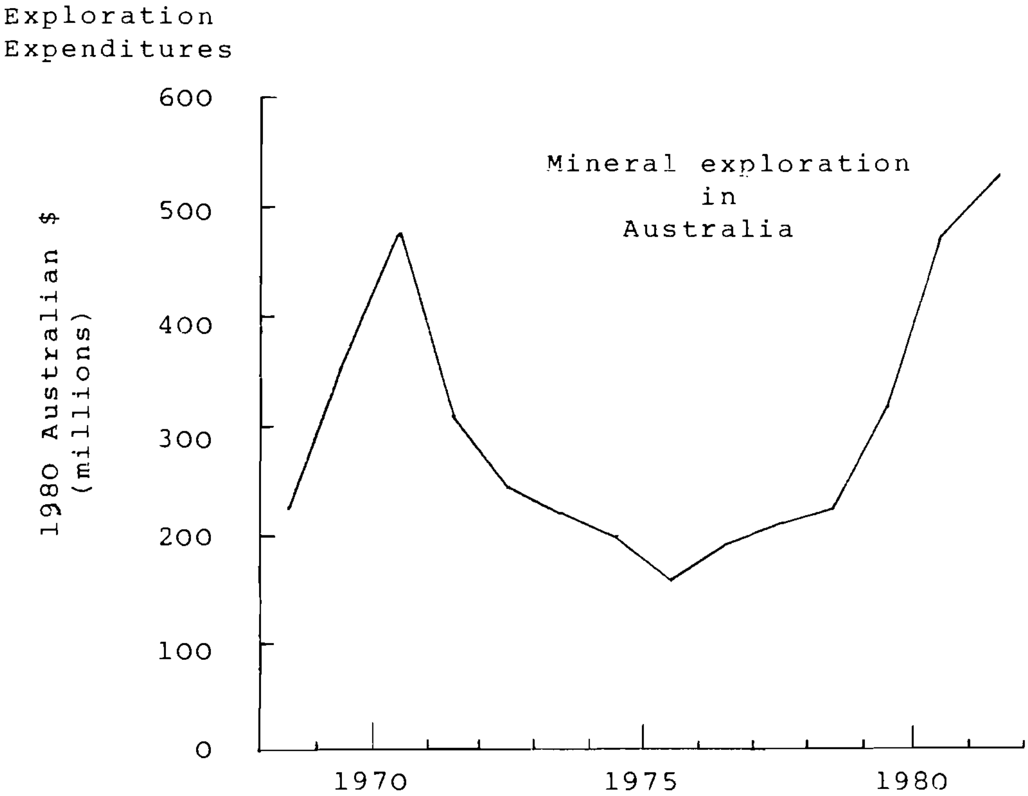

Figure 11. Australian mineral exploration expenditures by private organizations for fiscal years 1968-1969 to 1982-1983. Data exclude oil, gas, and oil shale, but include coal. Also excluded are expenditures on production leases of mines in operation or under development. Figures are deflated using the Australian GDP implicit price index. Source: Australian Bureau of Statistics, as reported in Crowson, 1983.

risks and to decline during periods of adverse policies and high risks. If, on the other hand, expenditure changes are unrelated to policies and risks, then one would expect the country's share of total expenditures to change in response to other factors.

As shown in Figure 12, Australia's share of total exploration expenditures (measured as the percentage of expenditures devoted to exploration in Australia) has varied widely over time for three firms and a group of European mining companies. In general, Australia's share increased substantially from the mid-1960s to 1973, declined from 1973 to 1977 (with the exception of the oil company), increased to record levels by 1980, and declined moderately since then.

The increase in share during the late 1960s and early 1970s, displayed in the European data, appears to be due largely to changing perceptions of Australia's geologic potential following a number of large mineral discoveries in areas previously believed to have little geologic potential. As discussed by Roberts (1977) and King (1973), significant discoveries of bauxite, manganese, lead, zinc, and particularly iron ore in the 1950s and early 1960s led to renewed interest in Australian exploration. The initial impetus seems to have been supplied by iron ore. King (1973, p.15) lists twelve important discoveries made between 1956 and 1965 (out of twenty-nine total mineral discoveries in Australia), made in part because of "the recognition of the great iron ore province in northwestern Australia" (Sullivan, 1974, p.20) and in part because of the proximity of the emerging Japanese steel industry, lying far from existing ore sources. During the same period, the Weipa bauxite deposit,

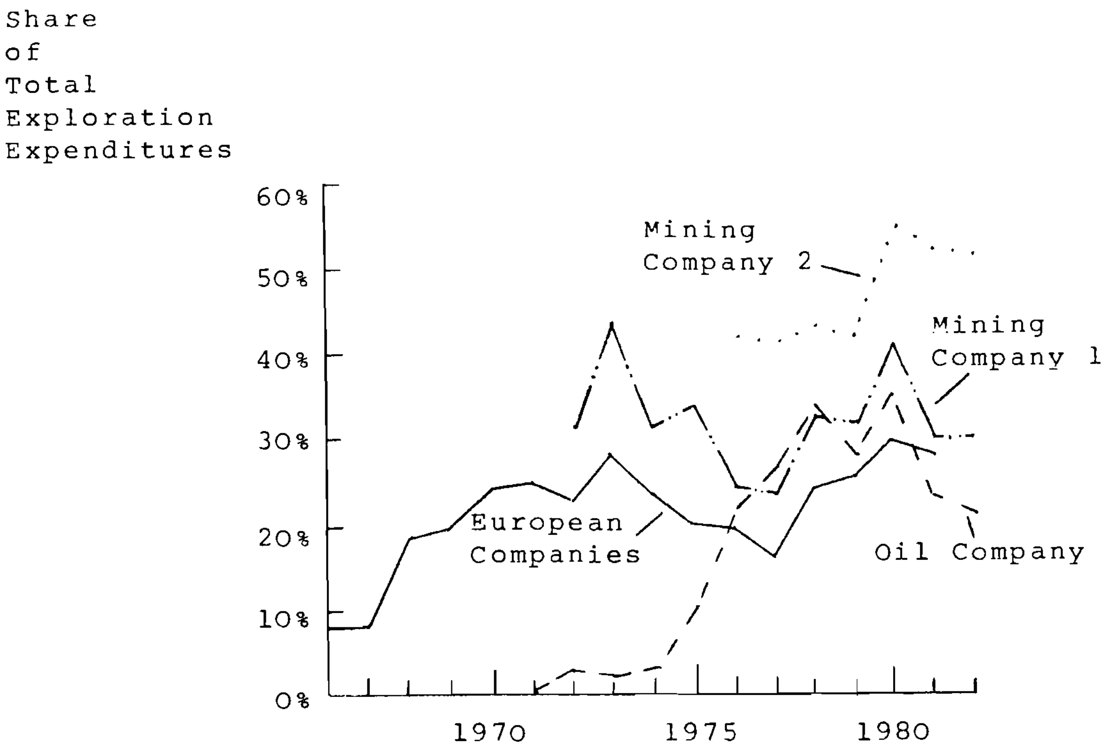

Figure 12. Australian share of total exploration expenditures. The data for the European companies (Crowson, 1983) and mining company 2 (obtained directly from the company) exclude expenditures for oil, gas, and uranium, but include coal. The other figures, also obtained directly from the companies, include only base and precious metals exploration.

the Macarthur and Woodcutters lead-zinc deposits, and the Groote Eylandt manganese deposit were discovered.

A number of discoveries in 1966, most notably the Kambalda nickel region in Western Australia and several phosphate deposits in Queensland, apparently sparked the exploration surge that lasted until the early 1970s. King lists fifty-eight mineral discoveries made in Australia between 1966 and 1973, including fourteen nickel sulfide deposits near Kambalda, in the area that, as noted by Sullivan (1974, p. 20), "was previously considered a gold province, and any mention that nickel might be present was generally regarded with great skepticism."

Returning to the effects of the Labor Party on metals exploration in Australia, it is readily apparent from Figure 11 that most of the decline in exploration expenditures occurred prior to the start of Labor Party rule in December 1972. Labor Party policies, therefore, could not have been directly responsible for most of the decline in exploration expenditures that occurred during the early and mid-1970s.

Nevertheless, there may be some merit to the view that uncertainty over future policy changes, as well as Labor policy changes themselves, discouraged exploration in Australia relative to other countries. From 1973 to 1977, Australia's share of exploration declined for the group of European mining companies and mining company #1, as shown in Figure 12. The uncertainty surrounding the future of foreign-controlled mining investment in Australia resulted from a number of actions including proposed restrictions on foreign-owned equity, conflict between the federal and state governments over who owned the mineral rights in certain regions, establishment of the Takeover Review Board to approve any arrangements between Australian resource owners and foreigners, and the consent required from aboriginal people to work on their land in the future.

Nonetheless, an equally-important cause of the decline in share appears to have been the success of exploration in Australia between 1956 and 1973. By 1973, the exploration boom may have run its course--that is, lacking important advances in exploration technology and concepts of mineral occurrence in Australia, significantly diminishing returns to additional exploration were reached. Moreover, the companies were worried about marketing what had been discovered already. As noted by Barnett (1980, p. 5), "so much iron ore, bauxite, and nickel had been found there was little point in funding further exploration."

From 1977 to 1980, Australia's share of exploration increased generally for the three firms and the group of European mining companies, as shown in Figure 12. This resurgence began about a year after the return of the Liberal-National Party coalition. Although the coalition eased some of the adverse Labor government policies, most notably restrictions on foreign-owned equity, there appear to have been other factors contributing to renewed interest in Australian exploration. Australia's geology is particularly attractive for gold deposits. The large increases in gold prices helped create "gold rush" conditions in Australia, where gold has been perhaps the most sought-after mineral in recent years (Oldham, 1981, pp. 54,59). As an example, gold exploration represented almost 40 percent of the oil company's Australian expenditures in 1982, compared with zero percent in 1978. In addition, since the late 1970s firms appear to have adjusted to new ground rules for exploration in Australia and other places around the world, and are more willing to participate in joint ventures with local partners, even in minority positions.

The United States

A number of changes in U.S. government policies over the last fifteen years, particularly land management regulations, are often cited as having made exploration and mining there less attractive relative to other areas. Concern over federal land management appears to have been especially high during two periods. First, in the mid-1970s the withdrawal of public lands in general from mineral development attracted much attention. In a much-quoted article, Bennethum and Lee (1975) estimated that the percentage of public lands withdrawn from locatable mineral development increased from 17 percent in 1968 to 53 percent in 1974. The frustration of many explorationists is exemplified by the following quote from Mullins, Lawrence, and Lalande (1976, p. 91):

> the practice of withdrawing federal lands from exploration and mining has accelerated to the degree that by 1980, if continued, all public lands could be closed.

Second, in the late 1970s concern centered around the closing of some Alaskan lands to mineral development, following several years in which Alaska was a favorite frontier area for many exploration groups (see for example, Mullins, and Lawrence, and Deschamps, 1977, p. 110; and Hodge and Oldham, 1979, p. 97). Many explorationists were disturbed by what they viewed as misguided policy. This frustration is evident in statements such as the following from Oldham (1980, p. 46):

> By May 1979, 68 percent of land considered to be within high-potential mineral belts had been formally closed to exploration and mining, the more recent withdrawals apparently being aimed specifically at these activities, and one calculation at this time indicated that only 17 percent of Alaska's total land area of 375,000,000 acres remained open to mineral exploration.

Nevertheless, as demonstrated below, it is far from clear that U. S. federal and state policies have been on balance more onerous or restrictive than policies in other countries.

Figure 13 displays how the U.S. share of overall exploration expenditures has changed since 1970 for three companies, and Table 2 provides less complete data from three other firms. The figure and table reveal no common and distinctive trends that would allow definitive conclusions to be drawn. For the oil company, the U.S. share declined sharply in the early 1970s as the company initiated exploration efforts in Canada and Australia; the share fell gradually from 1974 to 1980, and then rose in 1981. At Amax, the large increase in the U.S. share in 1974 probably resulted from greatly expanded exploration for energy minerals in the U.S.; in the late 1970s, the share increased largely because of large expenditures on detailed exploration and evaluation at Mt. Emmons (Colorado) and Mt. Tolman (Washington) molybdenum prospects. Asarco expenditures devoted to U.S. exploration appear to have increased gradually over the last ten years, although this inference is based on incomplete data. At Phelps Dodge, U.S. exploration has represented between one-half and two-thirds of nonenergy mineral exploration over the period.

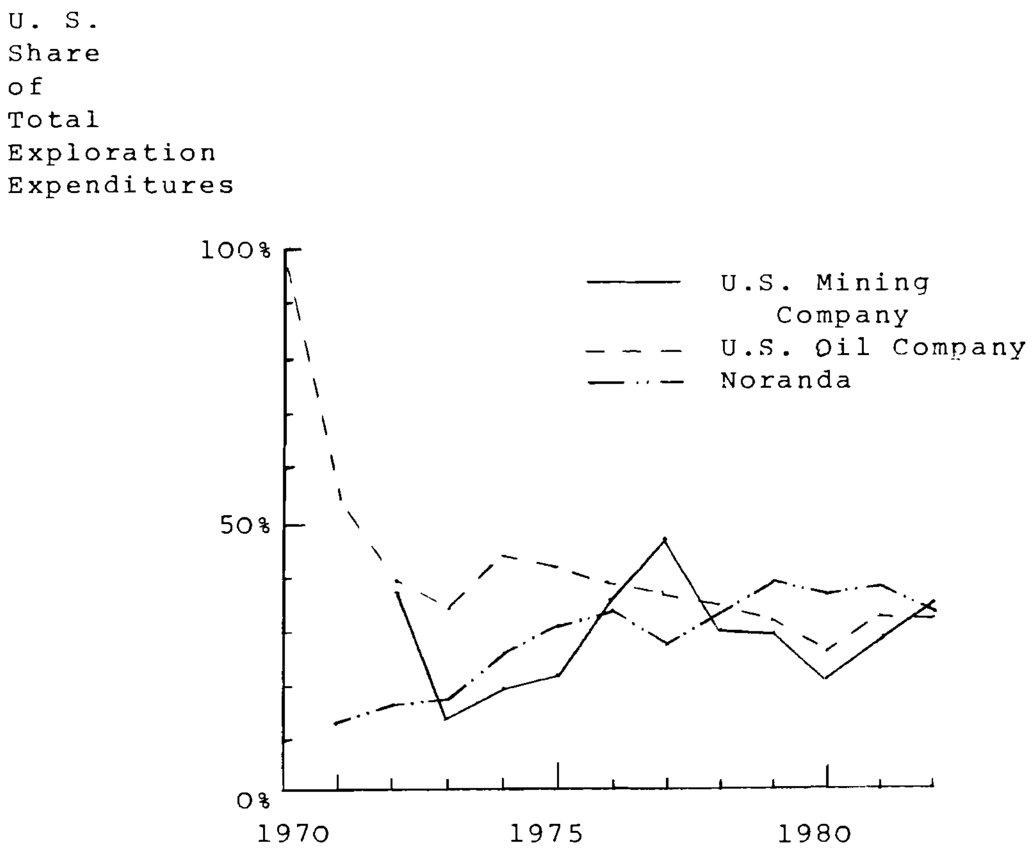

Figure 13. U. S. share of exploration expenditures for three companies. The U. S. oil and mining company figures were obtained in a confidential written survey. Oil company data include only base and precious metals expenditures. Mining company data also include a small component of uranium exploration. Noranda figures represent total metals exploration, as listed in company annual reports.

Table 2

United States Share of Exploration Expenditures for Three Firms

(percent)

Year	Amax	Asarco	Phelps Dodge
1972	54	> 50	n.a.
1973	45	ca. 50	ca. 50
1974	64	n.a.	ca. 50
1975	68	> 63	n.a.
1976	54	n.a.	ca. 50
1977	48	n.a.	ca. 67
1978	57	> 60	n.a.
1979	58	> 75	n.a.
1980	58	ca. 75	n.a.
1981	n.a.	ca. 75	ca. 65
1982	n.a.	n.a.	ca. 50

Notes:
n.a. = not available.
ca. = approximately
Source: annual reports.

For foreign exploration groups, on the other hand, one might reasonably conclude that U.S. policies on balance are very *favorable* for exploration, compared with policies elsewhere. According to Cook (1983, p. 12),

> the entry of foreign exploration companies into the U.S. will continue and possibly accelerate...The attraction of the U.S. for exploration is the political stability and generous foreign investment policies.

Exploration expenditures by Noranda in the United States have risen from 13 percent of total expenditures in 1971 to nearly 33 percent in 1982. Finally, Consolidated Gold Fields, based in London, spent over 80 percent of its direct or corporate exploration (that is, excluding expenditures by subsidiaries and partially-owned companies, such as Newmont) in North America, much of it in the United States (see Kramer, 1983). Nevertheless, these shifts toward the United States could just as well be due to other factors that offset any adverse effects of policy.

The implication, based on very incomplete analysis, is that there is no evidence to support the view that on balance U. S. government policies are any more onerous than those pursued by other governments, and they may even be more favorable than most.

Developing Countries

There is a widely held belief that exploration by major corporations has declined markedly in developing countries in recent years as a result of ill-conceived policies on the part of host governments and associated uncertainties regarding the potential for additional changes in the future. This has led to fears of future problems in mineral supply from developing countries. The purpose of this section is to assess the extent to which this proposition is true, using the limited amount of available evidence, and more generally to evaluate recent trends in the location of exploration activity in developing countries.

A group of European mining companies has collected statistics on the geographic breakdown of exploration expenditures by member firms for the period 1966-1982 (for details about the group, see Crowson, 1983). As shown in Figure 14, the developing country share of overall exploration (excluding uranium) fell from 45 percent in 1966 to less than 20 percent in 1970, with the steepest decline occurring in 1970 (from 42 percent to 18 percent). Since then the share has fluctuated between 9 and 20 percent of total exploration expenditures. One might infer that 1970 represents a watershed year in perceptions of political risk.

Resource nationalism in mineral-rich countries had been simmering since the early 1960s and appears to have reached a head in 1970 in its effect on exploration. In Mexico, the policy of Mexicanization required that "all new mining ventures including exploration had to be 51 percent Mexican," (Walthier, 1976, p. 46), even though operating mines had 20 years to comply. In 1964, President Eduardo Frei of Chile called for nationalization of foreign-owned copper mines, which ultimately occurred following the election of President Allende in 1969 (the nationalizations were not completed until 1971; see Moran, 1973). In Africa in the late 1960s, Zambia acquired controlling interest in its two largest mining groups, Anglo-American Corporation and Roan Selection Trust,

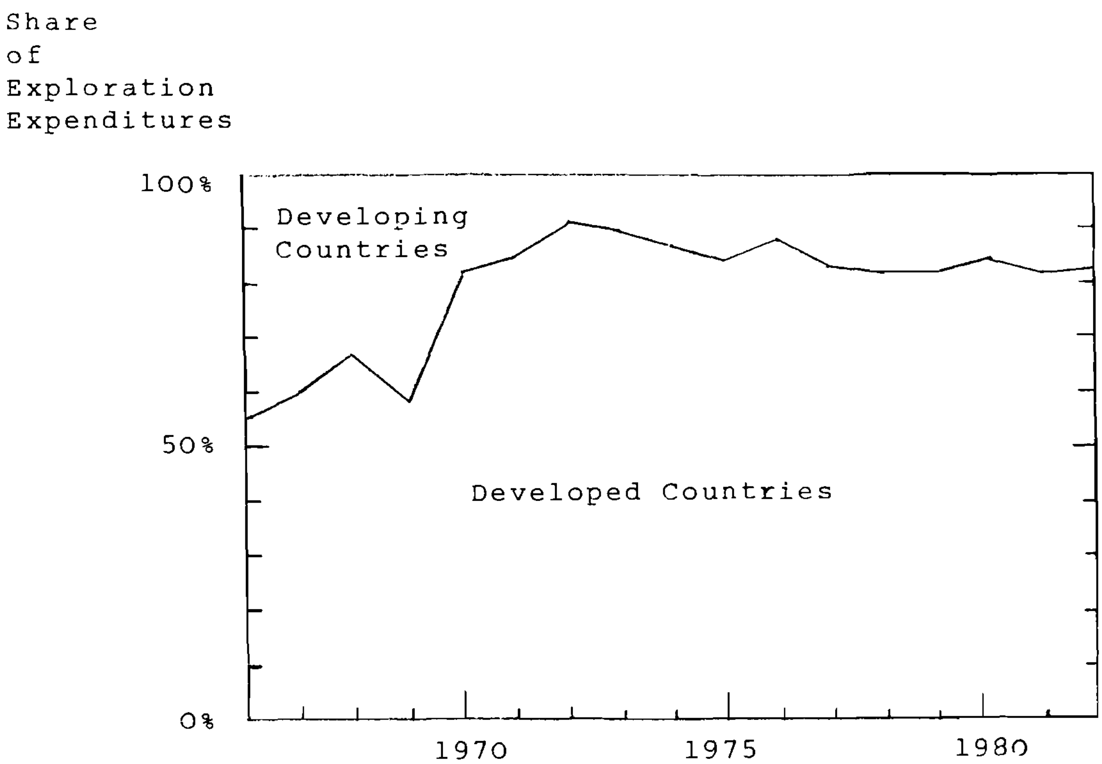

Figure 14. Developing country share of exploration expenditures for a group of European mining companies. Excluded are expenditures for oil, gas, and uranium exploration. Source: Crowson, 1983.

and Zaire nationalized Union Miniere's holdings there.

Thus, one might expect the big drop in shares in 1970 to be reflected in expenditures in these areas, namely Latin America and Africa (excluding South Africa). Nevertheless, the share of developing countries in Africa fell from only 3.7 percent to 2.5 percent in 1970, and the share of Latin America remained the same (at 0.6 percent), whereas the big decline in the developing country share reflects primarily a decline in Oceania, excluding Australia, from 21.2 percent in 1969 to zero percent in 1970 (Oceania held 11.2 percent and 12.0 percent in 1967 and 1968, respectively). Radetzki (1982, p.41) maintains that if the Bougainville copper project in Papua New Guinea is excluded from the statistics from 1966 to 1969, the decline in developing country share is much less dramatic---from 40 percent to slightly over 30 percent. Thus, a large part of the decline in 1970 reflects the movement of one project from the exploration to development stage, and not necessarily increased perceptions of political risk.

However, it is impossible to dismiss completely the role of government policies and political risks. The developing country share fell to 9 percent in 1972, while the share of Europe (presumably a less risky investment area) increased to over 30 percent in 1972 from 20 percent in 1970. Moreover, since 1970 the developing country share has been consistently lower than it was during a large part of the 1960s. Although these trends cannot be attributed solely to one factor, the resource nationalism of some developing countries in earlier years (highlighted above) must be considered a plausible contributing factor. Adverse policy changes toward mining companies and the specter of possible future changes can do nothing but raise the costs and risks and thus lower potential returns for a firm considering an investment in such a country, other factors remaining the same.

Nevertheless, there is some indication that corporate exploration in developing countries has increased in recent years, as companies have adjusted to new rules for operating in many developing countries and as countries have moderated some of their views and policies. As discussed by Davies (1983), many developing countries seem to be more willing to adhere to the provisions of a contract and to use national courts and international forums to settle disputes, thereby lowering the risks to a company operating in a developing country. Joint ventures, quite rare prior to the 1970s, are now commonplace, often involving several companies as well as the host government and offering a way of reducing the perceived risks of operating in a country.

The developing country share of exploration by the group of European mining companies increased from 9 percent in 1972 to 17 percent in 1982. Data from U. S. companies on their exploration activities in developing countries are much less complete than the data from the group of European firms. Nevertheless, as shown in Table 3, the share of expenditures devoted to developing countries by a U.S. oil company has risen from 0.5 percent in 1975 to 10.2 percent in 1982, and this may be representative of an increasing share of expenditures in developing countries by U.S. oil companies in general since the mid-1970s (Crowson, 1983, p. 15). Porphyry copper exploration in Chile has constituted a large part of this expenditure in the last several years.

Table 3

Developing Country Share of Exploration by a U.S. Oil Company

(percent)

Year	Developing Country Share
1973	2.3
1974	3.5
1975	0.5
1976	0.7
1977	0.7
1978	1.8
1979	8.3
1980	7.8
1981	11.6
1982	10.2

Source: data obtained directly from company exploration department.

This, in turn, appears representative of a trend toward increased exploration efforts in the Andean Cordillera, particularly Chile. A recent survey of large U. S. exploration groups by Barber (1981) indicates that 70 percent of the respondents either had active programs in Chile or were definitely planning them, making Chile the third most preferred foreign country for exploration, after Australia and Canada. For the group of European mining companies, the exploration share of Latin America rose from 4.6 percent in 1976 to 13.1 percent in 1981, and most of this activity appears to have occurred in Chile and Brazil.

What has caused the renewed interest in Chilean exploration? First, the Pinochet government has been much more receptive to direct foreign investment than was the Allende regime (which nationalized the foreign-owned copper companies in the early 1970s). A foreign firm in Chile can now own 100% of the equity in new mining interests, and new mining legislation, which became effective in December 1983, grants real property rights to foreign concessionaires (see *Engineering and Mining Journal*, 1984). Second, although Chile has long been geologically-attractive for exploration, several recent discoveries, including the Utah International-Getty Oil La Escondida porphyry copper deposit and St. Joe's El Indio gold-copper deposit, have stimulated exploration in areas that were believed to have relatively little geologic potential.

Returning to the fear that future mineral supplies from developing countries will be inadequate because of inadequate current exploration efforts there, the limited amount of data are clearly insufficient for making such an inference. The European data represent only part of overall corporate exploration expenditures. North American and other private corporations conduct significant exploration efforts in developing countries, and some evidence suggests that mineral exploration there by U.S. oil companies has increased since the mid-1970s. Furthermore, even if the developing country share of total private exploration expenditures has declined, exploration by public organizations, such as state-owned mining companies, may have partially replaced private exploration.

VI. SUMMARY AND CONCLUSIONS

Corporate mineral exploration responds to changing financial incentives, just like other types of investment. An interplay of economic, political, and technical factors influences expected revenues, costs, and risks, and thus expected returns from an investment in this particular activity.

The level of exploration expenditures varies to a large degree with changes in *overall* expected returns. Mineral prices strongly influence these changes by affecting potential revenues and thus the demand for exploration funds, and by altering costs and the supply of funds, through their effect on the availability of internal funds for financing exploration. In addition, a company's degree of exploration success and corporate goals such as diversification influence potential risks and revenues, and therefore returns from exploration.

The distribution of funds with respect to both commodities and countries tends to vary with changes in *relative* expected returns. In the first case, relative mineral prices are an important consideration, through their effect on potential mineral revenues. But other factors, such as changing discovery rates, advances in exploration and mining technologies, new exploration models, and corporate goals such as diversification, also influence expected returns and may be equally responsible for changes in this distribution of funds. In the second case, although government policies and political risks are an important determinant of expected costs and risks in a country, their importance has been exaggerated. Geologic criteria, particularly recent discoveries in an area, are probably the most important determinants of changes in the geographic distribution of funds. Nevertheless, to the extent that government policies and political risks discourage exploration in otherwise geologically and economically attractive areas, they create a nonoptimal distribution of exploration funds from the point of view of the world as a whole, unless other actors in the world of exploration, such as state enterprises, successfully take over the role played formerly by private corporations.

Accordingly, corporate mineral exploration must be viewed as an activity that competes for funds with other forms of investment that also serve to augment mineral supply. Exploration is not intrinsically good; rather, it is driven by the desire for lower-cost mineral production, and this goal can be reached by a number of means, including better production and processing techniques and further geologic research, as well as exploration.

Furthermore, corporate exploration can be relied upon to act in a systematic way to help limit the effects of depletion of mineral resources, if prices of mineral commodities accurately reflect their relative scarcity. As deposits of a mineral are depleted, the mineral's relative scarcity and price tend to increase. As expected returns from the production of the mineral increase, incentives to carry out more exploration also rise. Assuming that increased exploration leads to additional discoveries, relative scarcity declines and the specter of depletion subsides. Thus, to the extent that exploration by major corporations is representative of overall exploration, exploration acts systematically and in concert with material substitution and other forms of technologic change to help offset the cost-increasing effects of depletion.

APPENDIX: THE MINERAL PRICE INDEX

The mineral price index reflects percentage changes in real prices for the following minerals: copper, lead, zinc, gold, silver, molybdenum, nickel, and tin. Price changes are weighted according to the average value of mine production for the period 1971-1981. For each mineral, this average value was calculated by multiplying the 11-year average annual mine output by the 11-year average annual real price. Mine production figures represent production from market economy countries (that is, noncentrally-planned economies) and for all minerals other than molybdenum and gold were obtained from Metallgesellschaft, *Metal Statistics 1971-1981*, 69th edition, 1982. Gold and molybdenum figures were estimated from U.S. Bureau of Mines, *Minerals Yearbook*, various volumes.

As an example, consider a hypothetical index with two minerals, A and B. Assume that the average value of mine production for A represents 75 percent and for B represents 25 percent of the total value of mine production in the two mineral universe. If, in year t, A's price increases by 10 percent and B's price increases by 20 percent, then the price index will increase by 12.5 percent, as shown below:

$$(.75)(10 \text{ percent}) + (.25)(20 \text{ percent}) = 12.5 \text{ percent}$$

If the price index was 100 in year t-1, then it would be 112.5 in year t.

The following values for the price index were calculated:

1967	-	100.00	1975	-	162.16
1968	-	103.31	1976	-	153.50
1969	-	105.19	1977	-	158.15
1970	-	109.47	1978	-	163.08
1971	-	102.60	1979	-	220.11
1972	-	110.54	1980	-	266.00
1973	-	135.16	1981	-	222.83
1974	-	182.80	1982	-	192.64

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