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FOREWORD

One of the studies being carried out by the Mineral Trade and Markets Project is examining recent trends in metal trade patterns. As now envisaged, this study will contain four substantive chapters. The first will review changes in the location of metal mining over the last three decades, and attempt to identify the important determinants responsible for these changes. The second will focus in a similar manner on geographic shifts in metal consumption, while the third will investigate trends in the stage of production at which metal trade takes place. The fourth will analyze the role of transportation costs, political blocs, international ownership ties, and other factors that influence the choice of trading partners and introduce rigidities into international trade flows.

This working paper is a preliminary version of the first chapter concerned with the location of metal mining. It will be revised for publication when the other parts of the study are completed. The purpose of circulating it at this time is to elicit comments, criticisms, and suggestions for improvement.

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ABSTRACT

Substantial shifts in the geographic location of mining have taken place over the last three decades. These shifts, and the underlying factors causing them, are examined in this study of six important metallic commodities--bauxite, copper, iron, nickel, tin, and zinc.

The widely held belief that the developed countries, due to the exhaustion of their own mineral resources, are becoming increasingly dependent on the developing countries for the important minerals needed by their advanced economies receives little support. It is true that the United States and other highly industralized countries have seen their share of world mineral production fall. However, the growth of mining in Australia, Canada, and South Africa has largely offset this decline.

This study also concludes that the factor endowment theory of international trade is of some use in analyzing resource production and trade. A positive and generally significant relationship is found between reserves and production, which suggests that a sizable portion of the inter-country variation in mining can be attributed to differences in mineral endowment. The theory, however, offers no insights into why mineral endowments change over time, causing substantial shifts in the comparative advantage of mining. This, along with other identified shortcomings, means the factor endowment theory provides at best an incomplete explanation of mineral trade and production.

COMPARATIVE ADVANTAGE IN MINING

John E. Tilton

The depletion of high grade mineral deposits in the United States and other industrialized nations, it is widely believed, is forcing these countries to rely increasingly on imports, particularly from the developing countries, for needed supplies of metallic ores. This possibility raises a number of interesting questions. Specifically, how stable over time is comparative advantage in mining? Are the major producing countries of today the same as a decade or two ago, or have significant shifts in comparative advantage taken place? Where shifts have occurred, have they generally favored the developing countries? Perhaps of even more importance, why have there been shifts? Is mineral depletion in the industrialized countries largely responsible? More generally, what are the major determinants of comparative advantage in mining, how have they changed over time, and what have been the consequences?

This study examines such questions. It begins by reviewing recent trends in the location of mining for a number of the more important metals. It then examines the major factors responsible for the shifts in comparative advantage that have occurred over time.

A country is presumed to have a comparative advantage in mining if it is a major ore producer. Using this criterion, a country may possess a comparative advantage even though its costs of production are not particularly low relative to other countries. This could occur, for instance, where a government provides its mining sector with subsidies or protection from lower cost imports. Alternatively, a country may be a major producer simply because it developed substantial mine capacity during an earlier era when its costs were lower.

Thus, the term comparative advantage is used here in a broader sense than in many other studies. In particular, international trade theory, examined later in this study, generally assumes that comparative advantage depends solely on comparative costs. Indeed, the two terms are often used as synonyms in this literature. However, as this study is ultimately concerned with the ability of a country to produce metal products for export and domestic consumption, a broader use of the term comparative advantage seems more appropriate.

Patterns and Trends in Mine Production

While the mine production of all major metals has grown greatly over the last three decades, the market shares of individual producing countries have waxed and waned. Comparative advantage in mining, it appears, is a fickle friend. Within a period as short as twenty years it can shift sharply from one set of countries to another.

Bauxite in particular illustrates this phenomenon.[1] In 1950, Surinam, Guyana, and the United States together accounted for 60 percent of world production. By 1980, not one of these countries remained among the top three producers. Australia, whose output was negligible in 1950, was mining far more bauxite than any other country. Guinea had overtaken Jamaica as the second largest producer, and Brazil was embarked on an investment program that would make it a major producer during the 1980s.

In copper, the changes have been somewhat less dramatic. Still, Zambia and particularly the United States have yielded part of their share of world output to the Soviet Union, Poland, Peru, the Philippines, and other countries that produced little or no copper in the 1950s. In iron ore, U.S. production, which in 1950 exceeded the combined output of the next four producers, was surpassed by the Soviet Union in the 1950s, and then by Australia and Brazil in the 1970s. The market shares of France and Sweden, both major producers in the early postwar period, have also declined.

In nickel, Canada has watched its output drop from 76 percent of the world total in 1950 to 26 percent in 1980, while Australia and Indonesia have entered the industry and become significant producers. South Africa, a minor producer in the 1950s, also expanded its market share, as did New Caledonia, the second largest producer after Canada.

In tin, the changes have occurred at a slower pace. World mine output has increased, but more modestly, and one does not find new countries entering the industry and capturing a large share of world output. Still, shifts have taken place. In particular, Malaysia, Indonesia, and Bolivia have suffered a decline in their market shares, while the Soviet Union, Thailand, and Australia have garnered larger shares. Also, in Britain, where men have for centuries dug for tin, the long historical decline in comparative advantage has been reversed in the postwar period.

In zinc, the largest producer in 1950, the United States, accounted for over a fourth of world output. By 1980, its market share had fallen to six percent. Mexico, Italy, and Zaire also suffered reductions. In contrast, Canada increased its share of world production from 13 to 17 percent, and in the process became the world's leading producer, though the Soviet Union whose market share almost tripled over the period was by 1980 a close second.

While all the metals just considered display some shifts in comparative advantage over the postwar period, and surprisingly pronounced shifts in the case of bauxite, iron ore, and nickel, one does not find that these changes consistently favor the developing countries. As a group, the developing countries did increase their share of world iron ore and nickel production. Their share of total copper and zinc output, however, remained the same, and for bauxite and tin it actually declined.

Among the developed countries, it is true that the market shares of the more industrialized states have fallen for those metals where these countries are, or were, important ore producers. The share of world output coming from the United States, for example, decreased appreciably for all the metals examined except nickel and tin which the country has never produced in great quantities. Where the Western European countries and Japan are significant producers, as in the case of France for iron ore and bauxite, their market shares like those of the United States have tended to decline. These reductions, however, have been completely offset in bauxite and partially offset in copper, iron ore, nickel, and zinc by increases in market shares by Australia, Canada, and South Africa.

The socialist countries have over the last 30 years seen their share of world mine production fall for bauxite, remain about the same for nickel, and rise for copper, iron ore, tin, and zinc. Most of the increases for these last four commodities occurred during the 1950s. The Soviet Union is the principal producer in this group, and its mine output largely determines the performance of the socialist countries as a group. However, other socialist countries have had some influence: Hungary accentuated the decline in bauxite, Poland the rise in copper, and China the increase in copper, iron ore, tin, and zinc.

This short survey of trends in mine production raises the question of why the market shares of the major producing countries have so often changed, at times abruptly and substantially, over the last three decades. The search for an answer begins in the next section with a brief examination of international trade theory. Research in this field has long been concerned with the underlying causes of comparative advantage, and should be of some help in explaining international differences in metal mining.

International Trade Theory

The reasons why some countries produce and export certain goods, while other countries import these goods and export others, has interested economists for centuries. Modern explanations found in the pure theory of international trade are based on the doctrine of comparative costs developed by the classical economist David Ricardo over 150 years ago.[2] This doctrine maintains that states will produce and export those commodities whose domestic costs of production are low relative to other products when compared with production costs in other countries.

For example, if in the absence of trade, a particular basket of food cost two dollars and a given basket of clothing ten dollars to produce in the United States and 800 yen and 2,000 yen in Japan, food would be relatively less expensive in the United States. A basket of food would require only 20 percent of the cost of producing a basket of clothing, compared to 40 percent in Japan. As a result, the United States would tend to export food to Japan and receive clothing in return. Trade between the two countries could occur even though one country might be more efficient (and so possess an absolute advantage) in the production of both commodities, in the sense that its production requires less capital, labor, and other inputs. All that is required for trade is that the dollar-yen exchange rate be set so that it is cheaper for the United States to buy clothing from Japan than to produce it domestically (that is, the dollar must be worth more than 200 yen), and cheaper for Japan to buy American food than to produce it domestically (that is, the dollar must be worth less than 400 yen).

The doctrine of comparative costs is just the first step in explaining comparative advantage. For it to be of use, it is necessary to understand what generates or accounts for differences in comparative costs. Why, in the preceding example, does Japan enjoy a comparative cost advantage in clothing and the United States in food?

The classical economists were the first to answer this question. They maintained that differences in labor productivity were responsible. A farmer in the United States might produce three times the amount of food in a day as a farmer in Japan because of more favorable terrain, larger scale operations, and more highly mechanized farming techniques. Whereas American garment workers might produce only 50 percent more than their Japanese counterparts. While labor productivity can help explain differences in production costs, there are obviously other factors of production besides labor.

In the 20th century, Jacob Viner, Gottfried Haberler, and other neoclassical writers have tried to rectify this shortcoming of the classical explanation. They contend that differences in total productivity, rather than just labor productivity, are responsible for international differences in comparative costs. Differences in total productivity arise, they suggest, because the production function for goods varies from one country to another. The Japanese may apply the same amount of labor, machinery, and fertilizer to their agricultural sector and still not reap the same output per farmer as in the United States because of differences in weather conditions and land quality.

A second explanation for differences in comparative costs is found in the factor endowment theory, advanced by the Swedish economists Eli Hechscher and Bertil Ohlin in the early years of the 20th century. Their theory maintains that international differences in production costs are due largely to differences between countries in the price of capital, labor, and other factors of production, which arise because countries enjoy different factor endowments. The United States, for example, is well endowed with good farmland; Japan with people. Thus, the price of farm land in the United States is lower compared to labor than in Japan, and the United States enjoys a comparative cost advantage in the production of goods, such as food, that are land intensive.

Since World War II, other explanations for comparative costs have been proposed. These theories stress the importance of inter-country differences in technology, human capital, economies of scale, and domestic market conditions.[3] They are designed primarily to explain the large volume of trade that takes place between the industrialized countries in manufactured products. While differences in factor endowment and productivity do exist between these countries, they typically are small compared with those found between the developed and developing countries. Moreover, developed countries with apparently similar domestic conditions, such as those of Western Europe, often import substantial quantities of similar finished goods from each other. This has produced considerable uneasiness over the validity and usefulness of the neoclassical and factor endowment theories in explaining trade between such countries in automobiles, farm machinery, computers, and other manufactured products.

This dissatisfaction, however, does not extend to trade in primary products. Here, one still finds widespread acceptance of the factor endowment theory as the most useful explanation for international differences in production costs. In the case of metals and other mineral products, the applicability of the factor endowment theory appears almost self-evident. In the words of Haberler (1977, p. 4):

> The most obvious factors that explain a good deal of international trade are 'natural resources'--land of different quality (including climatic conditions), mineral deposits, etc. No sophisticated theory is required to explain why Kuwait exports oil, Bolivia tin, Brazil coffee and Portugal wine. Because of the deceptive obviousness of many of these cases economists have spent comparatively little time on 'natural resource trade.'

So Bolivia exports tin, Chile copper, and Jamaica bauxite because they are well endowed with these resources. Intuitively, at least, the hypothesis that mineral endowment is the overriding determinant of comparative advantage in metal production is very appealing. The next section examines this hypothesis more closely.

Mineral Endowment

Canada is the world's leading producer of nickel. Presumably this country is well endowed with nickel, but just how much nickel does it have? How does its endowment compare with that of New Caledonia, Indonesia, and other nickel producing countries? More generally, is there a close correlation between a country's endowment of nickel, or any other metal, and its production as the factor endowment theory contends?

Measures of Mineral Endowment

Before such questions can be answered, it is necessary to measure the mineral endowment that countries possess. There are several measures available for the purpose.[4] One possibility is mineral reserves. Reserves indicate the metal contained in deposits that are both known (discovered) and profitable to mine, given existing metal prices and processing costs.

A second measure is mineral resources. Resources include reserves plus the metal contained in deposits that would become reserves under specific conditions, such as the doubling of a metal's price or the discovery of all unknown deposits. Thus, resources give some indication of how reserves would change in the future assuming the specified conditions came to pass.

While reserves are difficult enough to measure accurately, the problems of estimating resources are far greater. Nevertheless, many efforts have been made and continue to be made to do so. These studies fall into two groups. The first attempts to indicate how the reserves of a metal found in known deposits increase as price rises (or production costs decline). The U.S. Bureau of Mines, for example, has estimated that the copper profitable to recover from known U.S. deposits increases from 11 to over 70 million tons as the price of copper rises from 0.50 to 2.00 (1978) dollars per pound.[5] The second set of resource studies focuses on the possible additions to reserves arising from new discoveries. The U.S. Geological Survey, for instance, has estimated that if all the copper deposits profitable to mine under existing economic, technological, and political conditions were found, copper reserves would increase in the United States by 57 percent and in the world by over 1000 percent (Erickson, 1973). Other studies in this group go further, in the sense that they attempt to estimate not only what exists but also how much of what exists is likely to be found.[6]

A third possible measure of mineral endowment is the resource base. This measure estimates the total quantity of a metal found in the earth's crust, and so reflects the ultimate physical endowment of the metal that a country possesses. It encompasses reserves and resources, and much more. While the copper reserves and resources of the United States were estimated at 78 and 122 million tons in 1973, the country's copper resource base totaled 45 trillion tons--more than 500,000 times reserves (Erickson, 1973). Unlike reserves and resources, this measure does not change over time, except for the relatively small quantities that are actually mined. It includes metals contained in discovered and undiscovered, as well as profitable and unprofitable, deposits. Indeed, it includes the metal found in common rock and other deposits of such poor quality that their production costs exceed by many multiples current prices.

All of the preceding measures provide estimates--and greatly different estimates--of mineral endowment for the world and for individual countries. Each has its own set of uses. For explaining comparative advantage and international differences in metal production, reserves appear most appropriate. For before production can take place, a mineral deposit must be discovered and developed, and only those deposits considered profitable are likely to be developed. Thus, while the resource base and particularly resources may influence future metal production, only metal endowments that are known and profitable to mine can affect current and past production.

It is important to note, however, that reserves are not fixed, but rather change as new discoveries occur, new technologies develop, and other conditions vary. As a consequence, to the extent comparative advantage in metal production rests on mineral endowment as measured by reserves, it may shift from one set of countries to another over time. Were the resource base the appropriate measure of endowment, once a relationship between it and metal production were demonstrated, the analyst could consider his job finished, for the resource base of any country is for all practical purposes fixed. Since this is not the case for reserves, finding a significant relationship between reserves and metal production simply raises another question: what forces determine the level of a country's reserves and cause that level to change over time? This important question is considered below, but first the relationship between reserves and production found among the major metal producing countries is examined.

Reserves and Mine Production

Following the discovery of a new deposit, a number of years are needed to bring it into commercial production. A U.S. Bureau of Mines study of eleven metal ore deposits in the United States, for example, finds that the time from discovery to production for the nine mines that are or soon will be operating varies from four to 13 years, and averages slightly over eight years (Gries, 1979, p. 3).[7] This gestation period arises because it takes time to conduct feasibility studies, plan the development, arrange the financing, negotiate with local governments over taxation and other matters, deal with the legal challenges raised by environmental organizations and other groups, strip the overburden for an open pit mine or sink the shafts for an underground mine, erect concentrators, construct transportation facilities, and carry out numerous other steps often involved in bringing a new mine into operation. If the mine is located abroad, it may also be necessary to build a town site and new port facilities, and perhaps work with the host government as a partner in the project.

The time interval between discovery and production suggests that in searching for a relationship between the reserves and mine output of countries one should expect the discovery of new reserves to produce an increase in output only after a lag of some years. It is for this reason that the 1980 mine output of the major producing countries of bauxite, copper, iron, nickel, tin, and zinc is compared in Figures 1a-f with their 1970--not 1980--reserves. Similar data for 1950 and 1960 are also shown to indicate how the relationship between these two variables has evolved over time.

Before examining these figures, it is important to note that accurate data on reserves are difficult to obtain, for they require comparable estimates from around the world on the amount of metal known to exist and profitable to exploit that is found in deposits being worked as well as those still undeveloped. Such information is gathered and processed by a variety of private and public organizations whose thoroughness and procedures are not always the same. Consequently, one cannot be certain that reported figures are consistent among countries or even over time for the same country. This is particularly likely to be a problem for those metals, such as iron ore, that are found in a relatively large number of deposits and countries. Reserves for the socialist countries may also be subject to relatively large errors, since information is often more difficult to obtain for these countries.[8]

Despite these problems, it is still useful to examine the relationship between reserves and mine output. Beginning with bauxite in the 1970s, one finds in the upper half of Figure 1a a tendency for 1980 production to increase with 1970 reserves. Guinea and Australia with the largest reserves are the largest producers, while Guyana, France, Greece, and the United States with reserves under 100 million tons all produce less than a million tons of bauxite.[9]

The solid line drawn in Figure 1a shows the linear relationship between bauxite production and reserves for developed and developing countries estimated by regression analysis. Although the amount of trade between the socialist countries and the market economy countries has been growing in recent years, historically such trade has been quite limited. As a result mine production in the socialist countries has responded primarily to the demand of socialist countries, while mine production in the market economy countries has responded to the demand of these countries. Under such circumstances, one would not necessarily expect the same relationship between reserves and mine production to exist in the socialist countries, and so they were excluded in estimating the relationship between these two variables.[10]

The major producing countries from the socialist group are, however, shown in Figures 1a-f, allowing one to determine whether the socialist countries produce more or less relative to their reserves than other major producing countries. With bauxite, for example, the output of the Soviet Union, the only major producer among the socialist countries, is higher than one would expect to find in market economy countries with comparable reserves.

The equation for the estimated relationship between 1980 production and 1970 reserves is also shown in the upper half of Figure 1a. The coefficient for the reserves variable (X), which gives the slope of the regression line, implies that an increase in reserves of one million tons raises the expected production of a country by 3.7 thousand (.0037 million) tons. Beneath this coefficient in parentheses is its standard error (.0009). An asterisk is placed after the coefficient if, as in the case of bauxite, the coefficient is statistically significant at or above the customary 95 percent probability level.[11] This means that it is highly unlikely--less than five chances out of a hundred--that the estimated positive relationship between 1970 bauxite reserves and 1980 mine production is due to mere chance.

Another important statistic in Figure 1a is the coefficient of determination (R^2). Its value of .71 implies that 71 percent of the variation among market economy countries in bauxite production can be attributed to or explained by variations in the size of their reserves. The figure also shows the number of countries (n) used in calculating the relationship between production and reserves, and the share of world output outside the socialist countries provided by these countries (S). In the case of bauxite, the nine countries identified in the figure produced 89 percent of the bauxite mined in the market economy during 1980.[12]

The significant relationship between bauxite production and reserves supports the factor endowment theory and the hypothesis that mineral endowment measured by reserves is an important determinant of comparative advantage in bauxite mining. Still, the fact that 29 percent of the inter-country variation in production is not explained by reserves should not be overlooked, for it suggests that other factors also affect bauxite production and comparative advantage in this activity.

Turning next to copper, one finds in Figure 1b that nine countries accounted for 87 percent of ore mined in 1980 in the developed and developing countries. The estimated relationship between 1970 reserves and 1980 mine production is even stronger than that found for bauxite. Expected copper mine output increases by 15 thousand tons per year for every million ton increase in reserves. The small standard error for this coefficient means the positive relationship between reserves and production is statistically significant, and the coefficient of determination suggests that 94 percent of the variation among countries in copper mine production can be attributed to differences in their reserves. Still, the figure does show that Canada and Chile produce somewhat more copper ore than expected on the basis of its reserves, and Peru somewhat less. It also indicates that the Soviet Union mines considerably more copper relative to its reserves than major producers outside the socialist group.

In iron ore, ten countries contributed 89 percent of 1980 world output outside the socialist countries. The estimated relationship between reserves and production indicates that a country's expected iron ore production increases by 3.4 thousand tons for every million ton increase in reserves. Again, the standard error for this coefficient is small enough to make this positive relationship statistically significant, and thus not likely the result of mere chance. According to the coefficient of determination, reserves account for 65 percent of the inter-country differences in production. Still, Canada, France, and Venezuela produce less iron ore than expected on the basis of their reserves, while the United states and Australia produce more. China is also found above the regression line, indicating that it mines more relative to reserves than is typical of the major non-socialist producers. The Soviet Union, on the other hand, mines somewhat less than expected, even though it is by far the world's largest iron ore producer.

In nickel, Canada, New Caledonia, and six smaller producers including Cuba (which is counted among the developing countries) produced 85 percent of the total output of nickel ore outside the socialist countries in 1980. An increase in reserves of a million tons raises expected mine production by 3.1 thousand tons. The probability that this finding is the result of mere chance, however, is higher than in the previous cases, for the coefficient of the reserve variable is statistically significant at only the 70 percent probability level rather than the 95 percent level. The coefficient of determination indicates that 11 percent of the differences among countries in mine production can be explained by their reserves. Australia and particularly Canada produce much more than their reserves would lead one to expect, while Cuba, the Philippines, and the Dominican Republic produce less. The Soviet Union mines more nickel relative to its reserves than is typical of the major non-socialist producing countries.

A second regression, which excludes Cuba, is shown in Figure 1d by the broken line. For two reasons, a reestimation of the relationship between production and reserves without Cuba seems desirable. First, Cuban reserves for 1970, and perhaps 1950 as well, may have been substantially overestimated. As Appendix Table 2d shows, the country's reserves for 1980 are less than 20 percent the levels reported earlier. While world reserves did decline somewhat between 1970 and 1980, this was due largely to the drop in Cuban reserves and cannot explain the latter. Second, the Castro revolution in Cuba in the late 1950s led to close political ties with the Soviet Union and other socialist countries. This realignment severed the financial and other connections the Cuban nickel industry had with the United States, and adversely affected the country's production and exports.

When Cuba is excluded, a million ton increase in reserves produces an expected rise in mine output of 6.4 thousand tons, rather than 3.1 thousand tons, and this coefficient is significant at the 90 percent level. The new results also indicate that 31 percent, as opposed to 11 percent, of the variation in country production can be explained by reserves.

In tin, ten countries produced 91 percent of the non-socialist output in 1980. The estimated relationship for these countries indicates that an increase in reserves of a million tons leads to an anticipated rise in production of 31.5 thousand tons, a figure which is statistically significant at the 95 percent probability level. Nearly 50 percent of the variation in country production can be explained by reserves. While Malaysia and to a lesser extent Indonesia and Bolivia produce far more than expected, Thailand produces less. Among the socialist countries, the Soviet Union mines more tin than predicted by the regression line, and China somewhat less.

In zinc, nine countries accounted for 72 percent of the zinc mined in 1980 outside the socialist countries. The estimated regression indicates an additional output of 20.6 thousand tons is associated with an increase in reserves of one million tons, and that this relationship is statistically significant. Although Canada, Peru, and Australia mine more zinc than expected and the United states less, half of the inter-country variation in the output can be attributed to differences in reserves. The Soviet Union, by far the most important producer among the socialist countries, mines considerably more zinc, given its reserves, than is typical of the major developed and developing countries. Other important socialist countries--Poland, North Korea, and China--produce approximately what one would expect or somewhat less.

The persistently positive relationship found in the 1970s between reserves and production raises the question of whether this relationship has been growing stronger over the postwar period. If so, this would suggest that other determinants of comparative advantage in mineral production have been declining in importance, and that in the future, particularly if this trend were to continue, one would be able to forecast the mine production of countries some years hence on the basis of current reserves. An indication of how the relationship between reserves and production has evolved in recent years can be obtained by comparing 1950 reserves with 1960 production and contrasting the results, which are shown on the right hand side of Figures 1a-f, with those just discussed. Not surprisingly, the findings vary depending on the metal.

For bauxite, a highly significant, positive relationship between production and reserves existed in the 1950s, just as in the 1970s. While Surinam produced appreciably more than expected and Greece less, 80 percent of the variation among countries in production is explained by differences in reserves, which is somewhat higher than the 71 percent figure for the 1970s.

For copper, too, a highly significant, positive relationship existed between production and reserves in the 1950s. While Canada lies appreciably above the estimated regression line for that period and Zaire and Chile below it, 87 percent of the inter-country differences in production can be explained by reserves. This is only slightly less than the high 94 percent recorded for the 1970s.

In iron ore, unlike bauxite and copper, a significant relationship between production and reserves did not exist in the 1950s. The horizontal slope of the regression line implies that the level of a country's reserves had little or no influence on its mine production. The United States and France were by far the largest producers among the non-socialist countries, even though their reserves were substantially less than those of India and Brazil. The world's largest producer was the

Soviet Union, whose reserves were little more than those of the United States. Thus, over the postwar period a positive and statistically significant relationship between iron ore reserves and production has developed where none existed in the 1950s.

In nickel, a similar, though somewhat weaker, trend appears to be taking place if Cuba is considered in estimating the relationship between production and reserves. In the 1950s there is no evidence that production increased with reserves. By the 1970s several new countries had begun mining nickel, and the output of the major producers appears to be somewhat influenced by their reserves.

If Cuba is excluded, and as pointed out earlier there are good reasons for doing so, one finds a positive, though statistically insignificant relationship between 1950 reserves and 1960 production for the remaining countries. Over the next twenty years this relationship grows somewhat stronger, and as noted earlier is significant at the 90 percent probability level by the 1970s.

In tin, the relationship between production and reserves was highly significant in the 1950s, and has remained so since. However, reserves accounted for only 47 percent of the differences in production among the major non-socialist producers in the 1970s compared to 85 percent in the 1950s.

In zinc, the relationship between reserves and production for the major producers outside the socialist group was negative and insignificant in the 1950s, and little or none of the differences in their output could be explained by reserves. By the 1970s the relationship was significant and positive, and could account for 53 percent of the intercountry differences in production.

Thus, for those metals, such as zinc, iron ore, and possibly nickel, where reserves had little or no influence on mine production in the 1950s, a relationship between these two variables has developed over the last several decades. For those metals, such as bauxite, copper, and tin, where production was already tied to reserves in the 1950s, this relationship has persisted. So by the 1970s reserves appeared to be an important determinant of comparative advantage in mine production for all of the metals examined, as the factor endowment theory would suggest.

Determinants of Reserves

This finding implies that one must examine changes in country reserves--and the underlying forces responsible for these changes--to understand the substantial shifts in mining that have occurred in recent years. Reserves for bauxite, copper, iron, nickel, tin, and zinc for individual countries, groups of countries, and the world are shown in Appendix Tables 2a-f for selected years over the 1950-1980 period. As pointed out earlier, the information on reserves is not completely consistent among countries and over time. Consequently, these tables must be interpreted with caution. Nevertheless, they do provide some indication of the major shifts in reserve holdings over the last 30 years.

Surprising, none of the six major metals considered exhibits a significant decline in the share of world reserves held by developed countries. The combined reserves of these countries have remained at about 35 percent of the world total for both copper and iron ore, and have increased for the other commodities–from 12 to 23 percent for bauxite, from 14 to 26 percent for nickel, from 2 to 7 percent for tin, and from 56 to 71 percent for zinc. Such figures provide little support for the widespread belief that the developed world is becoming increasingly dependent on the mineral wealth of developing countries as its own reserves are exhausted.

Within the developed countries, however, the location of reserves has shifted. The shares of the United States and other industrialized countries have fallen, while those of Australia, Canada, and South Africa have grown. This suggests that the industrialized countries may have to rely more heavily on mineral imports, but that these imports are likely to come increasingly from other developed rather than developing countries.

The developing countries have seen their share of world reserves increasefor bauxite from 66 to 73 percent, and remain about the same for copper at 52 percent. For the other metals considered, their share has declined--from 55 to 32 percent for iron ore, from 86 to 60 percent for nickel, from 73 to 68 percent for tin, and from 28 to 19 percent for zinc. Within this group, significant changes have also occurred in favor of the Philippines, Indonesia, Brazil, New Caledonia, and Guinea, and against Zambia, Zaire, Malaysia, Cuba, India, and Jamaica.[13]

In the socialist countries, reserves have grown from zero to 13 percent of the world total for nickel and from 11 to 33 percent for iron ore, but have fallen from 22 to 3 percent for bauxite and from 16 to 10 percent for zinc. Copper reserves climbed from 13 to 24 percent during the

1950s, but by 1980 were back down to 12 percent. Conversely, tin reserves as a percentage of the world total declined during the 1950s and 1960s, and then recovered during the 1970s reaching their 1950 level of 25 percent in 1980.

The reserves held by individual countries and country groups may change over time for three reasons: (1) the exploitation of known deposits tends to deplete reserves; (2) changes in technology, metal prices, and the cost of factors of production may increase or decrease reserves; and (3) the discovery of new deposits adds to reserves.

Mining consumes a country's reserves, and thus tends over time to reduce them. Eventually, a mineral deposit is exhausted. In practice, this tendency is often partially offset, and at times entirely offset, by development work that occurs at operating mines. Most firms are reluctant to incur the expense of proving the reserves of new prospects beyond the equivalent of 20 to 30 years of production. Further development work is postponed until the mine is in production, when operating revenues can be used to support the search for more reserves. At some sites, a foot of diamond drilling is then carried out for each ton of ore mined. At other properties, similar rules of thumb are followed. As a result, new additions to reserves slow the decline over time in the ratio of reserves to annual production. This explains why many mines continue to operate long beyond their initial life expectancy.

Nevertheless, countries do deplete their reserves and in the process lose their comparative advantage in metal production. The decline of bauxite in the United States, for example, can be attributed in part to the exhaustion of known deposits.

It is far from inevitable, however, that major mining countries will find their reserves declining over time. Indeed, as Appendix Tables 2a-f illustrate, very few countries have suffered an absolute reduction in mineral reserves over the postwar period. Part of the explanation is that many known deposits in the early postwar period, which were not then economical to mine, have since become so due to (a) an increase in metal prices, (b) a fall in mining and processing costs, or (c) a decline in transportation costs.

The prices of most metal products have risen over the last several decades, even after adjusting for inflation. Zinc was the only major metal considered whose real price fell between 1950 and 1980. It declined by 9 percent. Real prices rose by 17 percent for aluminum, 17 percent for copper, 75 percent for steel, 94 percent for nickel, and 112 percent for tin.[14] Such increases add to reserves by making previously marginal deposits profitable to exploit.

The cost of mining and processing metals may fall over time for two reasons. First, the cost of factors of production used in producing metals, such as energy, can decline. Over much of the postwar period, the real price of energy did fall, though this favorable trend came to an abrupt end in the 1970s as a result of the OPEC oil cartel and other developments. Second, and more important, processing costs may decline because of technological developments. In mining, larger trucks, shovels, and other earth moving equipment have been introduced, and better blasting techniques developed. New technology has pushed costs down as well at the concentration, smelting, refining and fabrication stages of production.

New processes have also allowed the winning of metals from completely new types of ores. The economic extraction of iron from taconite, for example, helped prevent a decline in U.S. iron ore reserves over the postwar period. Similarly, new technologies facilitating the commercial exploitation of laterite deposits greatly expanded nickel reserves in the Dominican Republic and elsewhere.

Transportation costs have fallen substantially over the last 30 years as a consequence of larger ore carriers, more automated port facilities, and other advances. The dramatic impact of these developments on the cost of shipping iron ore is highlighted by McDivitt and Manners (1974, pp. 36-38):[15]

> The charge for moving ore between Brazil and Japan in the middle 1950s ranged between $16 and $20 per ton . . . . With the introduction of oil/ore carriers on a quadrangular trade in the late 1960s, the rate fell yet further to $4 per ton. Such a fall from $20 to $4 might represent an extreme case; yet declines of 50 and 60 percent in iron ore freight rates on particular runs are not difficult to find in the period 1950 to 1970.

The decreases for other mineral commodities are typically smaller, for seldom can the firms in these industries ship their output in the quantities required to fill giant ore vessels and realize the resulting economies of scale (Wittur, 1974, pp. 153-155). Still, new developments have lowered shipping costs in other metal industries as well, albeit on a somewhat smaller scale.

In addition, for some countries the rise of nearby markets has reduced mineral transportation costs. During the 1960s and early 1970s, for example, Japan enjoyed extremely rapid economic growth, and nearby producing countries found the cost of shipping mineral products declined as Japan replaced Western Europe and the United States as their major market.

The fall in the per ton-mile cost of shipping bulk commodities and the rise of Japan have particularly helped producing countries in the Far East, such as Australia, Indonesia, New Caledonia, and the Philippines. This is one reason why the share of world reserves held by these countries has increased in recent years for many metals.

Changes in technology, metal prices, production costs, and transportation costs can reduce reserves as well as increase them. The rapid adoption of the basic oxygen furnace in the production of steel, for example, initially increased the preference for iron ores with low phosphorous content (Manners, 1971, p. 49). This adversely affected the price of high phosphorous ores found in the Benelux countries, France, and Sweden, and contributed to the slow growth of reserves in these countries during the 1960s.

Similarly, falling metal prices have on occasion forced mines to close and turned ore into worthless rock. Increases in construction costs, interest rates, energy costs, and environmental costs have at times pushed production costs up in certain countries; and now and then transportation costs have risen. All such developments tend to reduce reserves.

The third reason for changes in reserves is the discovery of previously unknown deposits. New discoveries are the product of exploration which is largely carried out by private firms, particularly the multinational mining corporations. Just what factors firms consider in deciding how much to spend on exploration, where to look, and what types of mineral deposits on which to concentrate is far from clear. Presumably firms undertake exploration because they anticipate a financial return from this activity. The expected profit depends on the probability of finding one or more deposits, and their value once found. These two considerations depend on geological, geographical, economic, and political factors.

Looking first at the geological factors, one finds that economic deposits contain metal in far greater concentration than is found in common rock. The cutoff grades for aluminum and iron ore deposits are 2.2 and 3.4 times the average crustal abundance of these metals (Cook, 1976, p. 678). For other metals, the ratio of cutoff grade to crustal abundance is far higher. It is, for example, 56 for copper, 100 for nickel, 370 for zinc, and 2000 for tin.

A number of other considerations are also important in determining whether a deposit is worth developing. The presence of valuable byproducts, such as gold or silver, may allow the mining of a copper deposit below the normal cutoff grade, while a deposit containing arsenic or other costly impurities may not be economic even though it exceeds the cutoff grade. The size of the deposit can also be important. Porphyry ore bodies averaging less than 0.5 percent copper can be profitably mined because they are large enough to reap the substantial economies of scale that can be realized with modern mining, processing, and infrastructure facilities, while higher grade but smaller massive sulfide deposits remain too costly. Deposits located close to the surface are also likely to be more economic than deeper, but otherwise comparable, deposits, since surface mining with an open pit is generally cheaper than underground mining. Another important factor is the nature of the ore. Nickel from laterite deposits costs more to produce than nickel from sulfide ores, even when the grade is similar, because laterite ores cannot be concentrated and so must be entirely treated by relatively expensive pyrometallurgical or hydrometallurgical techniques.

Specific geological conditions are required to create ore bodies with the grade and other qualities necessary to make them profitable. As a result, such deposits are not uniformly distributed over the earth's crust, but are concentrated where the necessary geological conditions once existed. Consequently, companies tend to focus their exploration on those areas appearing most favorable in terms of their geological history. In practice, this often means those regions where deposits have been discovered in the past. The western parts of the United States and Canada, for example, are much more heavily explored for porphyry copper deposits than other parts of these countries.

It would be a mistake, however, to assume that firms consider only geological factors in allocating their exploration expenditures. For companies, no matter how favorable the geological potential, will not spend significant sums of money looking for bauxite in areas distant from port facilities. The low value of bauxite and the high cost of shipping it over land generally means even a good deposit located far inland is uneconomic. Similarly, in the past, the high cost of shipping bauxite, iron ore, and other low value ores and concentrates discouraged exploration in countries, such as Australia, situated far from the main markets. As pointed out above, however, this situation has recently changed in response to the falling costs of shipping bulk commodities and the rapid growth of the Japanese market.

Another important geographical consideration is the availability of infrastructure. The mining and processing of metals requires the movement of substantial quantities of materials. This calls for a transportation network that often includes roads, railroads, and port facilities. In addition, metal production requires people, and they need schools, power facilities, homes, stores, churches, sewers, recreation facilities, and all the other amenities required to make a townsite. Where such facilities already exist, either because mining is being carried on in the region or because other industrial activities are there, the costs of developing a new mine are far less. For example, Driver (1972, p. 67) has estimated that the costs of developing an open pit copper mine in a remote area, such as northern Canada, may run as much as 75 percent above the costs of a comparable mine in an established copper mining region, such as Arizona. As a result, other things being equal, firms have an incentive to concentrate exploration on those areas where a heavy investment in infrastructure is not necessary.

Changes in technological and economic conditions also affect exploration. It was pointed out earlier that shifts in processing costs and metal prices can influence a country's reserves by making marginal deposits either profitable or unprofitable to exploit. Such changes can likewise affect exploration. For example, as rising nickel prices and new processing technologies made laterite deposits a more attractive source of nickel during the 1950s and 1960s, firms became interested in exploring for such deposits in countries such as Australia and Indonesia, where the conditions were favorable. More recently, this interest has waned as rising energy costs and depressed nickel prices has made the mining of most laterite deposits unprofitable.

Finally, exploration is influenced by political conditions. Where taxation and other government policies favor the mining industry, as was the case in Australia, Canada, South Africa, and the United States over the 1950-1970 period, the value of any new discovery is enhanced. This increases the incentive to carry out exploration in such locations. Alternatively, unfavorable government policies discourage exploration. After a long history of preferential treatment toward the mining sector, Canada in the early 1970s sharply increased mineral taxes. A conflict between the federal and provincial governments over the division of mining taxes exacerbated the situation, and in some provinces mining firms found their effective rate of taxation actually exceeded 100 percent of profits. The consequences were dramatic. Canadian mining firms conducted 60 percent of their exploration outside the country in 1975, compared to only 20 percent in 1971 (DeYoung, 1976, p. 33).

Political stability is also important. Coups, riots, and war can interrupt the production and transportation of ores. They can also make it difficult to retain highly skilled workers and managers from abroad. Firms have little incentive to look for new deposits in countries where the likelihood of such events is high.

More on the importance of political factors is found in the next section. The focus there, however, is on the impact of the political environment on mine development rather than exploration.

Other Determinants of Mine Production

While reserves, and in turn the various factors effecting changes in reserves, significantly influence mine production, some countries produced much more or less than expected on the basis of their mineral reserves alone. Canada, for example, mines more nickel than anticipated, and Cuba much less. Australia and Jamaica mine more bauxite than expected, and Guinea and Brazil much less. These deviations imply that other important determinants of mine production exist and need to be considered.

Other Factors of Production

Mining involves more than just good deposits. The drills, trucks, crushers, rod mills, shafts, infrastructure, and other necessary facilities require capital, usually in large amounts. In addition, labor is needed to run and maintain the equipment, and to provide the necessary technical and managerial skills. Energy and material supplies are also essential.

However, these factors are relatively mobile. The major mining firms have for many years been willing to take their capital along with their managerial and technical expertise to remote corners of the world to develop and operate new mines, as long as the political risks were not too great. As a result, international differences in the endowment of capital and expertise are of secondary importance in the location of mining facilities. Of greater significance are the legacy of past investment and the political environment.

The Legacy of Past Investment

The capital invested in a mine cannot be recovered by closing down the facility. As a consequence, it pays to continue producing from an existing mine, rather than develop a new one, as long as the average out-of-pocket (variable) costs of production at that facility, including the cost of necessary repairs, are lower than the average total costs of a new mine. Since capital costs are normally a large part of total costs, once a mine is constructed it will generally not pay to replace it before the associated ore body is depleted.[16] This means that changes in the geographic distribution of reserves and other developments affecting international differences in production costs will have their full impact on the location of mining only after a time lag equal to the life of existing mines.

If the life expectancy of most mines were short, this would not significantly retard the adjustment of production capacity and comparative advantage among metal mining countries caused by changing conditions. But, as is well known, this is not the case. Most major mines remain in operation for at least 20 to 30 years, and some carry on for much longer. Many of the major copper mines developed in the 1920s, for example, are still being worked today. Some are even producing more ore now than they did then.

The long, productive lives of mines, coupled with the importance of capital costs, tend to prolong the dominance of established mining districts long after the conditions that promoted their rise have changed in favor of other producing areas. Moreover, this tendency is reinforced by two other considerations. First, as pointed out earlier, new mines can be developed more cheaply in established mining areas where an adequate transportation system and other forms of infrastructure are already in place. Second, and somewhat related, it is often less expensive to create new capacity by expanding existing mines than by building new ones. At existing facilities, administrative and overhead costs typically do not rise in proportion to the increase in capacity. This may also hold for maintenance costs. In some cases, capacity can be increased by minor investments that alleviate existing bottlenecks, rather than a complete replication of existing mining facilities.

The benefits of exploiting existing mines until they are exhausted, of developing new mines in established mining districts, and of adding new capacity by expanding existing facilities help explain why the United States mines considerably more iron ore and Canada more nickel than expected solely on the basis of their reserves. The large Malaysian output of tin may also be due in part to such considerations, though this is less certain. Much tin mining is conducted by relatively small operators whose capital investment compared to other metal miners is limited. Consequently, they can more easily and quickly move into and out of mining.

The rigidities introduced by past investment are greatest for those metals whose output is expanding slowly. Rapid growth requires the construction of new mines even though existing mines may not be in need of replacement, which accelerates the shift from traditional to new mining regions. For this reason, it is not surprising that the greatest changes in mine location are found for those metals, particularly aluminum, whose output has grown rapidly in recent years.

Major changes in technology which lower mining costs but require a substantial investment in new facilities also tend to accelerate geographic shifts in mine production by shortening the life of older facilities. As do government regulations, such as environment restrictions, which are cheaper to comply with when building new mines than by modifying existing mines.

The Political Environment

Just as the political environment can encourage or discourage exploration, it can affect investment in new mine capacity. Specifically, government policies and actions can change the expected costs, risks, and revenues associated with metal mining, and in the process alter the investment decisions of the multinational corporations and other companies accounting for most new investment in metal mining over the last several decades.[17] Even the best metal deposits can be made too costly to mine through heavy taxation, royalties, exchange controls, environmental regulations, requirements to use domestic services and goods, and demands that domestic ores be processed internally. In addition, policies that promote widespread discontent domestically while suppressing peaceful change, as well as belligerent foreign policies, may encourage civil disruptions and war, and thereby raise the risks associated with new mining ventures to an unacceptable level.

The impact that public policies can have is illustrated by the shifting location of new iron ore mines since World War II. Following the war, large American steel companies turned to Canada, Venezuela, and other foreign countries to develop new iron ore mines. In part, this move reflected concern over the depletion of high grade deposits in northern Minnesota, but another consideration was the desire to diversify sources of supply. During and before the war, the industry depended heavily on ore from the Iron Range of Minnesota where the state and local communities near the mines imposed heavy taxes on the companies. By developing mines abroad, the companies increased their bargaining power vis-a-vis these governments, and thereby reduced their vulnerability to high taxes (McDivitt and Manners, 1974, p. 47).

Shortly after World War II, U.S. Steel and Bethlehem established iron ore mining subsidiaries in Venezuela, and greatly increased their imports from these facilities during the 1950s. As a result, Venezuelan mine capacity grew rapidly, and the country's output increased from 0.1 to 11.9 million tons between 1950 and 1960 (Appendix Table 1c). In the late 1950s, however, a new government came to power in Venezuela. It claimed that the two American companies had substantially underpaid their taxes over the 1953-1958 period by understating the value of their iron ore shipments from Venezuela. This provoked a dispute that dragged on for years encouraging both U.S. Steel and Bethlehem to look elsewhere for their growing needs of iron ore.[18] As a result, during the 1960s when iron ore capacity was growing rapidly in Canada, Brazil, and elsewhere, production in Venezuela stagnated.

In the middle 1970s, the political climate changed once again. Sharp increases in taxes in Canada and Australia, along with other considerations, prompted American steel companies to look favorably once again on northern Minnesota and Michigan for their new investments in iron ore capacity (Hollister, 1978, Chap. 7).

Not all government policies raise production costs. Indeed, on many occasions governments have subsidized mining by constructing necessary transportation facilities, granting generous tax holidays, providing inexpensive electric power, and offering other benefits. For example, the Hanna nickel deposit at Riddle, Oregon, the only producing nickel mine in the United States would almost certainly not have been developed without the strong support of the U.S. government. The latter agreed in 1953 to build a smelter for the company's use at a cost of 22 million dollars and to sell the smelter to the company at salvage value at a later date. Hanna exercised this option in 1961, paying only 1.7 million dollars (Cameron, 1977, pp. 171-174). This greatly reduced the firm's capital costs, a major component of the total costs of producing nickel.

Nor is the Hanna experience unique. In the 1950s, the French government built a new dam at Yate in their colony of New Caledonia to provide the power for the electric furnaces being installed by Societe Le Nickel, the principal producer in New Caledonia, in the company's first major expansion in many years (Cameron, 1977, p. 121). A more recent example of the importance of government support is provided by the rapid rise in aluminum processing capacity in Britain during the late 1960s and early 1970s, which was stimulated in part by the 40 percent plant and machinery and 25 percent building grants the British government made available to new firms in development areas (Warren, 1973, p. 199). In the zinc industry, Hillman (1976) finds so many instances of government subsidies and other actions affecting production costs, that he concludes public policies have had an overwhelming impact on the quantity and location of new investment in this industry.

In the socialist countries, political considerations have had an even greater impact on mine production. The major producer in this group, the Soviet Union, has through its development programs tried to minimize dependence on foreign sources of mineral ores, even though for some metals, such as aluminum, this has required the use of low grade, high cost deposits. This effort to achieve and maintain self-sufficiency is one of the principal reasons why the Soviet Union mines more of most metal commodities relative to reserves than is typical of major producers among the market economy countries.

Government actions also influence the risk associated with mineral ventures. Major mineral projects today require hundreds of millions of dollars, and in some cases, billions of dollars. The Caujone mine in Peru, which produced its first ton of copper ore in 1976, cost over 700 million dollars (Mikesell, 1979, p. 128). As a result of inflation, this project would now cost well over a billion dollars. Firms must be particularly sensitive to the political environment in deciding where to locate such capital intensive projects.

Among the various concerns covered by political risk is the possibility that host governments will subsequently raise taxes. As noted earlier, Canadian mining firms were caught in the middle of the conflict between the federal and provincial governments in the early 1970s. The higher taxes that ensued in some cases eliminated all profits. A more common story is for a firm to negotiate an agreement with a host government prior to developing a new mine and then find that the government demands a renegotiation of taxes and other terms after the project is successfully on stream (Bergsten *et al.* 1978, Chap. 5).

Expropriation is another type of political risk. Even when a firm is compensated for its invested capital, it loses the return it hoped to realize on that capital, as well as the managerial and technical talent it invested in the project. In 1960, Freeport Minerals lost its nickel operation in Cuba as that country increasingly turned toward socialism. Other well known examples include the nationalization of the copper facilities owned by Anaconda and Kennecott by Chile in 1971, the iron ore properties of U.S. Steel and Bethlehem by Venezuela in 1975, and the bauxite facilities of Reynolds by Guyana in 1971.

Political risk encompasses more than just confiscatory taxation and expropriation. Changes in environmental regulations, restrictions on the remittance of profits or dividends abroad, requirements to construct domestic processing facilities, and other policies affecting the operation of mineral ventures can turn a profitable operation into a financial liability.

Although multinational firms have demonstrated considerable ingenuity in devising various means, including project financing and joint ventures with host governments, to reduce political risks,[19] the latter has nevertheless influenced the pattern of new mine investment in many metal industries. This is illustrated by recent shifts in copper mining. During the 1950s, mine capacity increased rapidly in Peru, Zambia, Zaire, and to a lesser extent Chile, as the low grade ore found in most unexploited deposits in the United States, the world's largest copper producer, discouraged expansion there. During the 1960s, however, political risk in these four developing countries increased considerably. In Chile, where Anaconda and Kennecott had encountered some problems with the government even in the 1950s, hostility toward foreign control of the vital mining sector grew more threatening during the 1960s. In the early years of that decade, some foreign managers could already see the clouds of increasing government intervention and even expropriation gathering on the horizon. Similar risks arose in the neighboring state of Peru later in the 1960s.

In Africa, Zaire after winning its independence in 1960 promptly became embroiled in a civil war. Then within several years, it nationalized its copper industry. Its neighbor, Zambia, became independent from Britain in 1964, and shortly thereafter demanded majority control of the copper firms operating within its territories.

The deteriorating political environment in these countries altered the flow of investment funds. While large, high grade copper deposits remained untouched in Chile, Peru, and other developing countries, the multinational mining corporations developed deposits of far lower grade and quality in countries considered politically more stable and safe. Ten new mines, for example, began operations in western Canada between 1959 and 1972. The average ore grade was less than 1.0 percent for nine of these deposits, and less than 0.6 percent for seven (Galway, 1975, pp. 42-43). The developed countries, whose share of world mine production dropped from 48 to 41 between 1950 and 1960, not only reversed this trend but modestly increased their share of world output during the 1960s. Among the developing countries the only major producer that managed to increase its market share was the Philippines. Nor was this a coincidence, as the country was considered relatively stable and secure.

Governments can influence investment patterns in yet another way, through policies that give firms, usually domestic firms, preferential access to markets. This allows the favored firms to charge higher prices, earn greater revenues, and realize larger profits than would otherwise be possible. Earlier it was pointed out that the U.S. government stimulated the development of the Hanna nickel deposit in Oregon by building a smelter and then selling it to the company at far below its historical cost. In addition, the government guaranteed the company a market for its nickel at a price that covered its smelting costs plus a premium return on its ore. Although the Riddle deposit was quite poor compared to undeveloped deposits in Canada and elsewhere abroad, the contract with the government assured the company a profitable project. In fact, Hanna's Nickel Division was very profitable, as net income averaged 39 percent of total income after taxes over the 1954-1960 period, a rate considerably above what the company earned on its non-nickel activities (Cameron, 1976, pp. 171-174). Nor is the Hanna experience unique. Similar U.S. government contracts with Falconbridge allowed that firm to expand its nickel mine capacity in Canada.

Although public policies affecting the cost, risk, and revenues of mineral ventures are of greatest importance, other policies also distort mineral investment. International Nickel, for example, contemplated developing new nickel deposits in New Caledonia in the early 1960s but was rebuffed by the French government which simply refused to approve its application. About the same time, the company also considered a new mine in Guatemala, but the government there demanded a joint venture and the company backed off. For such reasons, International Nickel eventually increased its mining capacity in Canada (Cameron, 1976, pp. 60-64), helping to accentuate the sharp difference in the ratio of nickel production to reserves between Canada and New Caledonia found in Figure 1d.

This study has looked at comparative advantage in metal mining, and found that there is not one but a number of important determinants of production. A simple application of the factor endowment theory, which maintains that countries are major producers of bauxite, copper, and other metal ores simply because they are well endowed with the requisite minerals, suffers from several deficiencies. First, it is often not clear what is meant by mineral endowment, or how such an endowment should be measured. The most appropriate measure appears to be reserves, which considers only those deposits that are both known and profitable to exploit.

Second, mineral deposits and the ores they contain are just one input needed for mining. Other factors of production, particularly capital and technical and managerial know-how, are also essential. Endowments of these resources, like reserves, vary greatly among countries. As they are more mobile internationally, however, they have not been a major determinant of comparative advantage in mining and the location of mine production.

Third, the factor endowment theory overlooks the attractions of established mining districts that tend to reinforce and perpetuate the comparative advantage of these areas. In exploration, firms look for new deposits where the geological conditions are believed favorable. This often leads to areas where good deposits have been discovered in the past, for at such locations the necessary geological conditions for the genesis of ore bodies are known to have existed. Once a mine is developed, the capital sunk into the facility inhibits for many years its being replaced by a new mine elsewhere simply because production costs there become somewhat more favorable. In addition, it is usually cheaper to expand existing capacity than to build entirely new mines; and when new mines are called for, they are often less expensive to build in established mining regions where the necessary transportation network, power facilities, and townsites are already available.

Fourth, in metal mining, government policies and other political considerations can greatly affect both expected returns and risks. Indeed, many countries well endowed with high quality deposits have not been able to attract the necessary capital and expertise to develop their mineral wealth either because they have, through high taxes and other means, tried to take too large a share of the potential returns, or because they have been unable to provide the political stability required by investors when committing hundreds of millions of dollars.

Finally, the factor endowment theory is an incomplete explanation of comparative advantage for yet another reason. Since the international distribution of mineral endowments, as measured by reserves, evolves over time, to the extent that such endowments are an important determinant of mine production, the theory takes only the first step in explaining differences in comparative advantage. On the important question of why country endowments, and in turn comparative advantage in mining, shift over time, it is silent. These shifts are caused by the exhaustion of operating mines, exploration and the discovery of new deposits, and changes in technology, prices, input costs, and the political environment. The important factors causing changes in the worldwide distribution of reserves must be considered along with the other important determinants before a full explanation of comparative advantage in mining is achieved.

Footnotes

[1]Appendix Table 1a shows bauxite production in thousands of tons of metal content for the world as a whole, for groups of countries, and for the principal producing countries at ten year intervals over the period 1950-80. It also indicates the share of world production contributed by the major producing countries. Similar information for copper, iron ore, nickel, tin, and zinc is found in Appendix Tables 1b - f.

[2]Surveys of the pure theory of international trade through the early 1960s are found in Haberler (1961) and Bhagwati (1964).

[3]For a review of these theories, see Vernon (1970), particularly the chapter by Hufbauer (1970).

[4]For more on how mineral endowment might be measured, see Brobst (1979), Brooks (1976), McKelvey (1973), Schanz (1975), and Zwartendyk (1972).

[5]These estimates, which were made to illustrate the Minerals Availability System of the U.S. Bureau of Mines, are based on a number of specific assumptions regarding required rate of return, taxes, byproduct credits, and other relevant factors (Davidoff, 1980). Why the upper figure given--70 million tons--is less than the reported U.S. copper reserves (see Appendix Table 2b) is not entirely clear, though it appears that undeveloped copper properties were not considered in the analysis. In an

earlier study (Bennett, *et al.*, 1973), the U.S. Bureau of Mines has estimated that a rise in the price of copper from 0.50 to 0.75 to 2.00 dollars increases U.S. reserves from 75 to 104 to 163 million tons. See also Babitzke, *et al.* (1982).

[6]For a survey of geostatistical techniques used for resource evaluation, see Harris (1975) and Harris and Skinner (1982).

[7]Cook (1980) analyzes the lead-time between the decision to develop a mine and its start-up for twelve metal-mine projects. He also provides data on the lead-times for 33 copper mines in his Table 1, which vary from under two years to seven years. These lags exclude the time that elapses between the discovery of a deposit and the decision to develop it, and so are shorter than those reported by Gries.

[8]In addition, the sources for the reserve data, which are identified in Appendix Tables 2a-f, do not always report information for all countries and country groups of interest. This has necessitated that certain figures be estimated, as the notes to Appendix Tables 2a-f indicate.

[9]Reserve and production figures are throughout this study measured in terms of metal content.

[10]While conceptually this separation is desirable, in most cases the estimated regression line did not change greatly when the major socialist countries were included in the analysis.

[11]Since the coefficient is expected to be positive, a one tailed test is used.

[12]The samples of countries (n) used in estimating the regression lines shown in Figures 1a-f are small, particularly for nickel and zinc. This means that one or two countries may greatly affect the results, as is shown to be the case for nickel. While one might for this reason question the usefulness of the regression results, it should be noted that the samples examined are not simply random selections of producing countries. With few exceptions, the countries examined together accounted for 75 percent or more of all production outside the socialist countries.

[13]The huge decrease in Cuban nickel reserves, as pointed out earlier, is probably in part due to deficiencies in the data.

[14]Metal prices are average yearly prices from American Metal Market, *Metal Statistics* (annual).

[15]For more on the changing costs of shipping iron ore, see Manners (1971, Chaps. 9-10) and Vogel (1981).

[16]The boundaries of some ore bodies are not clearly delineated, as their ore grade tends to taper off gradually. In such cases, a fall in metal prices can make marginal reserves uneconomic to mine, and result in the mine closing somewhat sooner than otherwise.

[17]State enterprises have become more important in recent years in many metal industries. Government owned mines, for example, now account for over 40 percent of the world's copper production outside the socialist countries. However, taking over and running an operating facility is easier than developing an operating mine. As a result, state enterprises account for a smaller share of new mine investment than of world mine output.

[18] For more information on this dispute and its consequences, see Gomez (1971).

[19] For an interesting description of how Kennecott attempted to protect its interests in Chile through project financing, see Moran (1973). For more on the problems posed by political risk and the means firms have employed for coping with these problems, see Moran (c. 1980).

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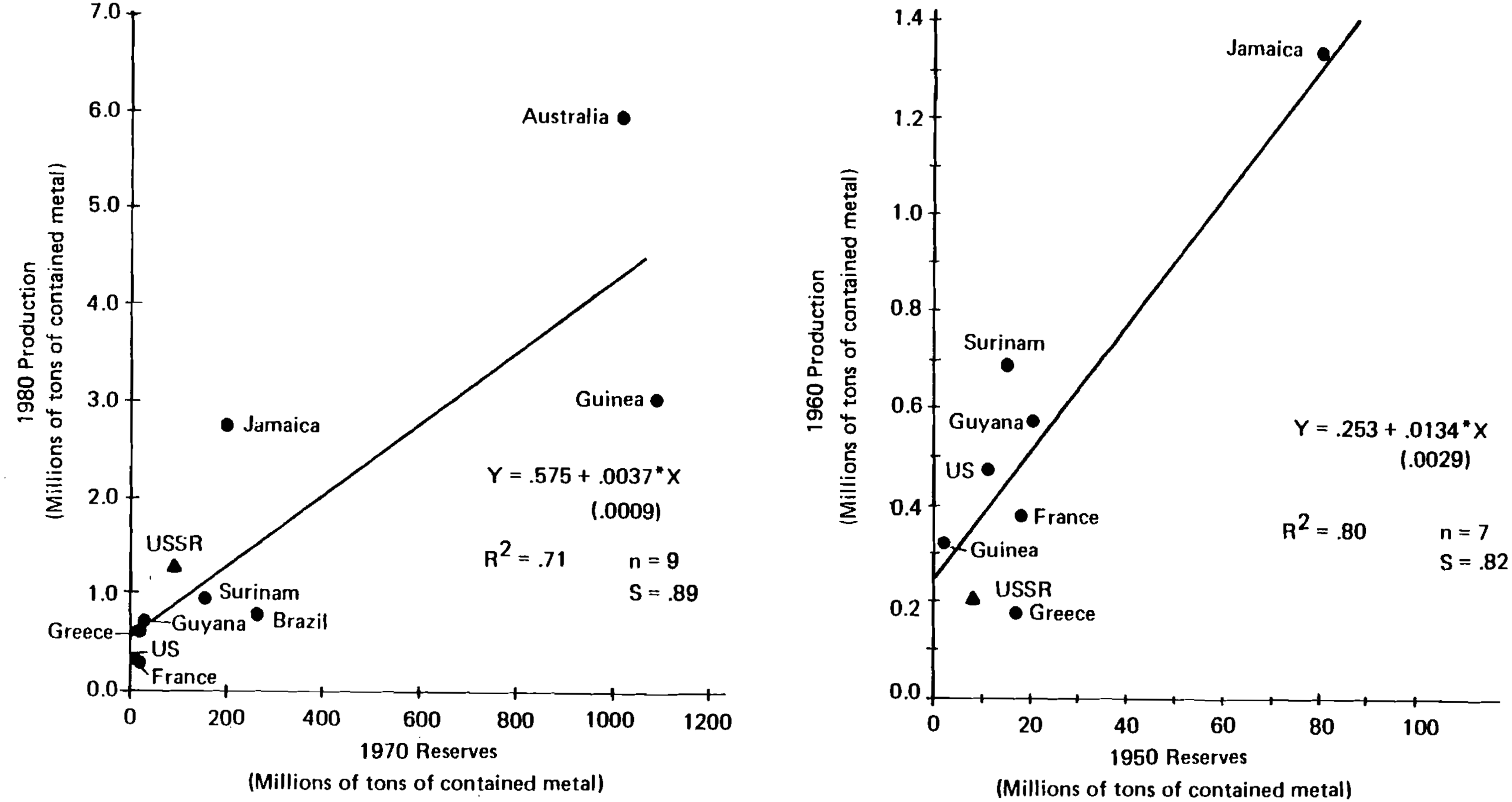


Figure 1a. Reserves and production of bauxite for the major producing countries[a]

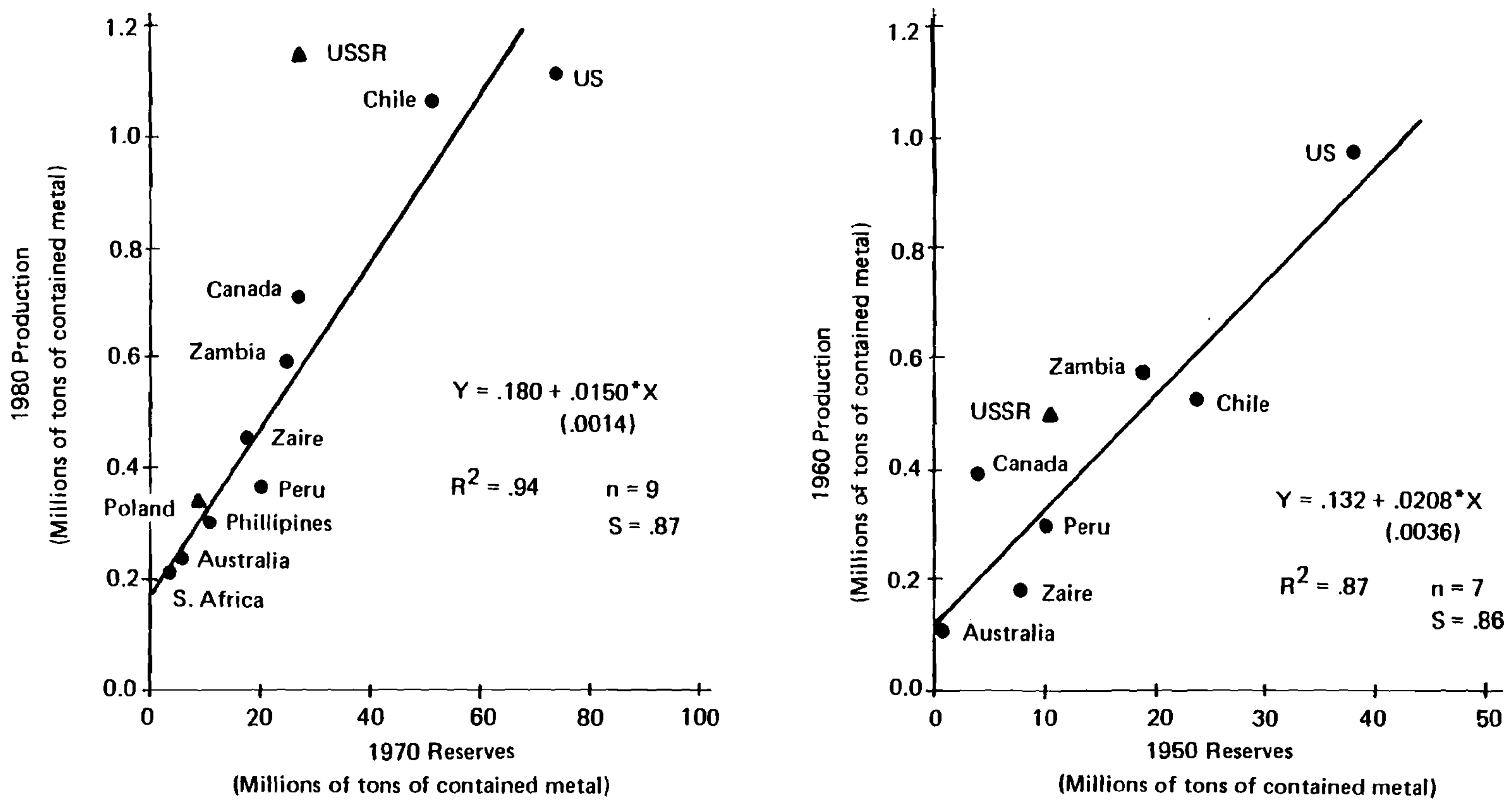


Figure 1b. Reserves and production of copper ore for the major producing countries[a]

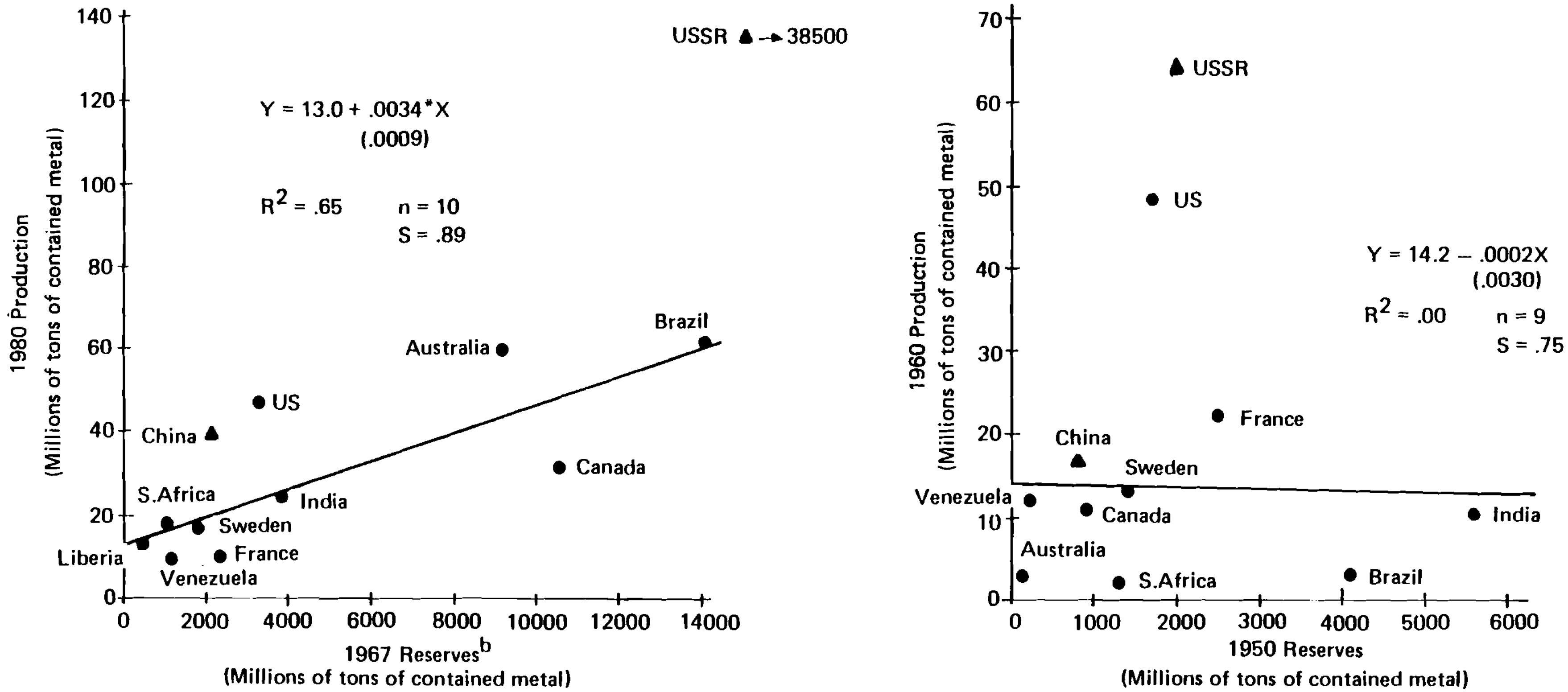


Figure 1c. Reserves and production of iron ore for the major producing countries[a]

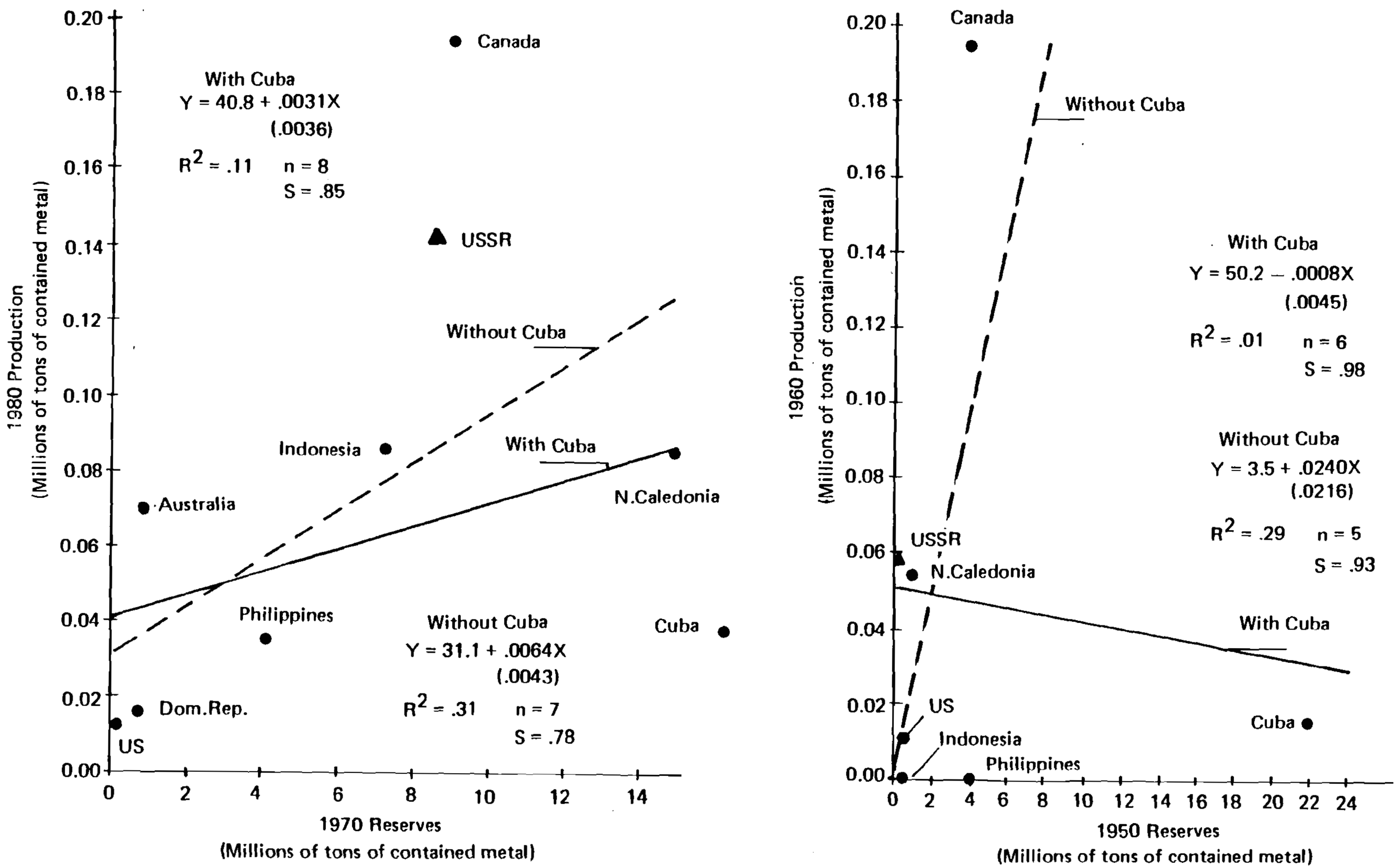
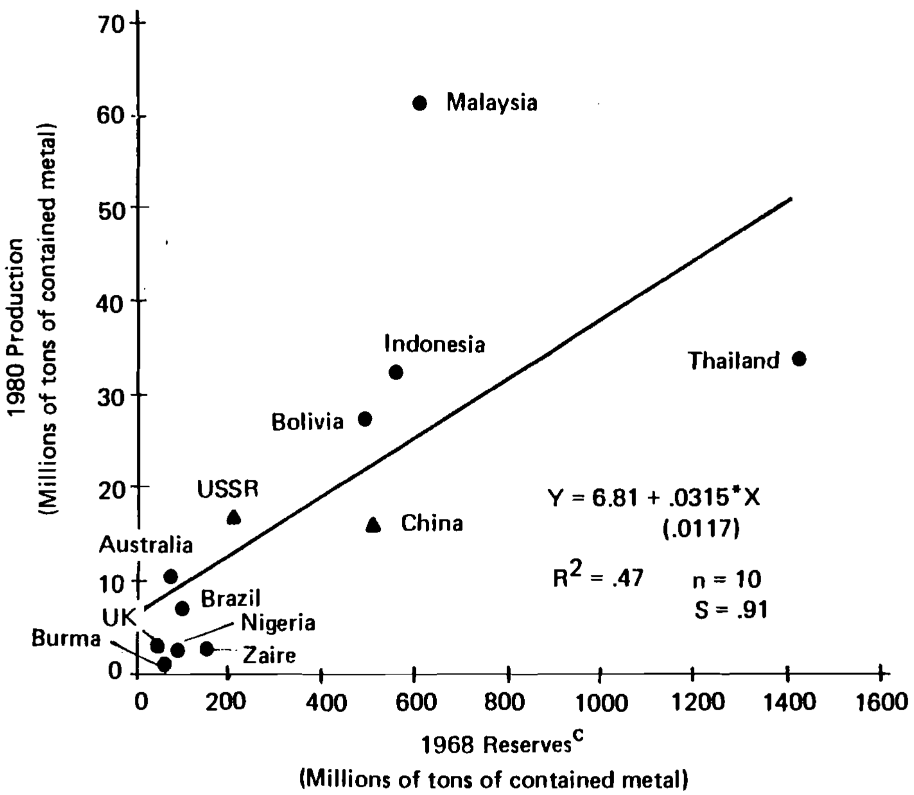


Figure 1d. Reserves and production of nickel ore for the major producing countries[a]



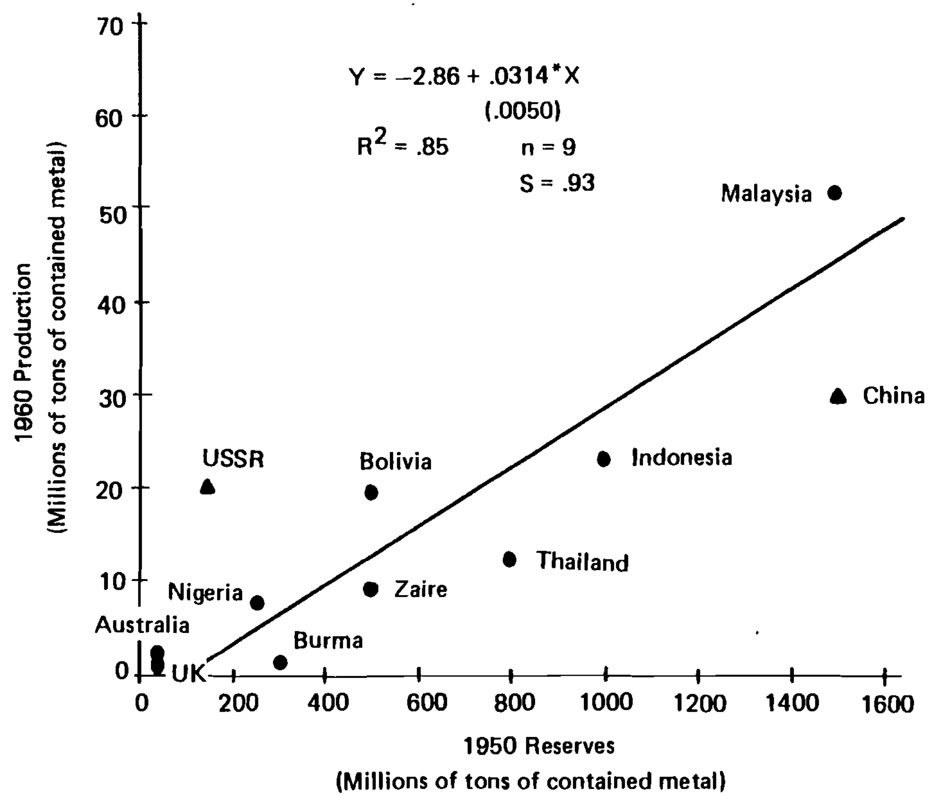


Figure 1e. Reserves and production of tin ore for the major producing countries[a]

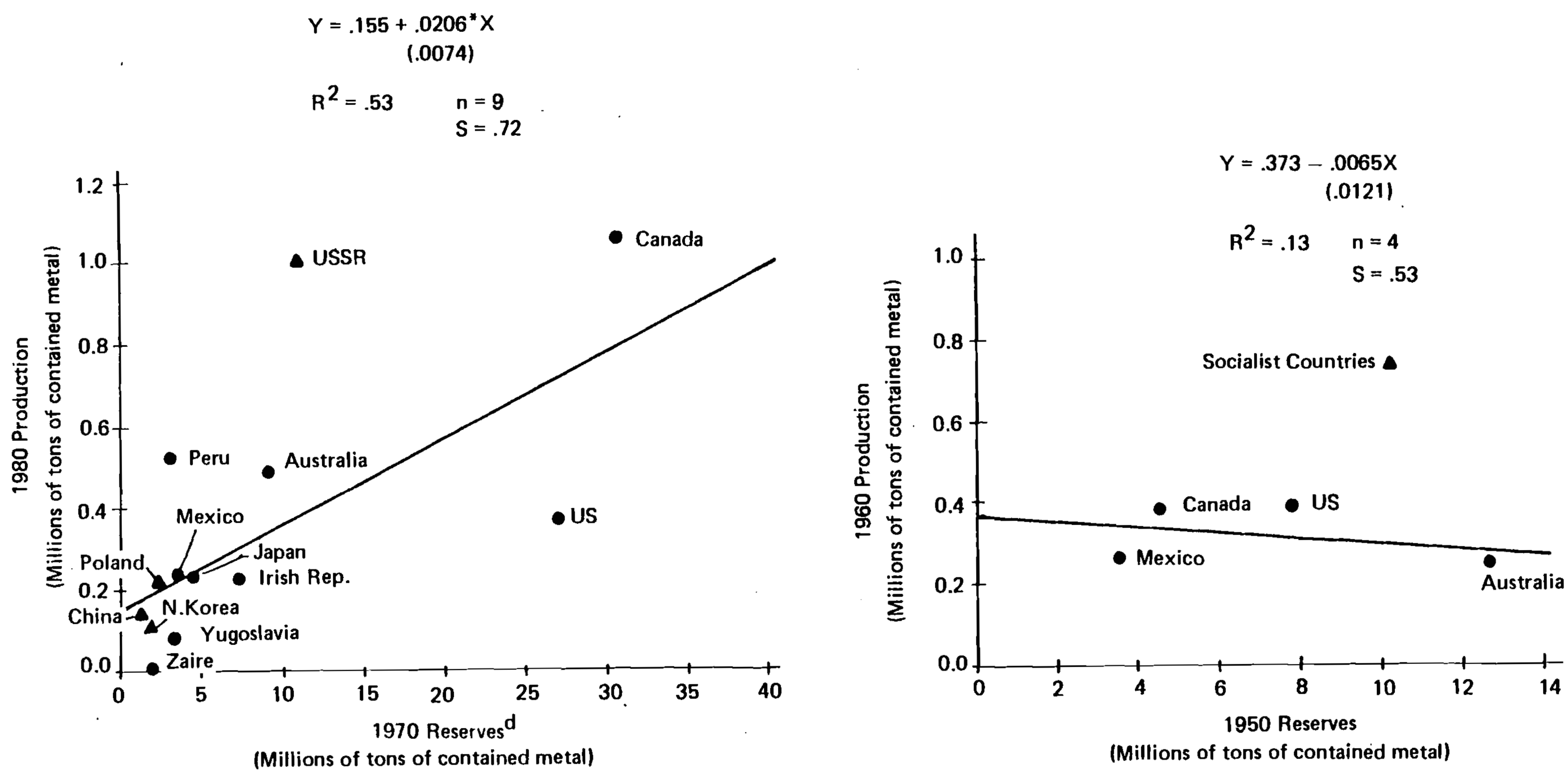


Figure 1f. Reserves and production of zinc ore for the major producing countries[a]

Notes:

[a]Major producing socialist countries are identified in figure 1 by a triangle rather than a dot, and were not considered in estimating the relationship between production and reserves.

[b] The closest year to 1970 for which iron ore reserve data are available is 1967.

[c]The closest year to 1970 for which tin reserve data are available is 1968.

[d]Zinc reserves for 1970 for all major producing countries other than Australia, Canada, Mexico, and the United States are estimated based on 1975 reserve figures.

Sources: Appendix Tables 1 and 2.

Appendix Table 1a

Mine Production of Bauxite by Country and Country Group, Selected Years, 1950-1980[a]

	1950		1960		1970		1980	
Country and country group	Thousands of tons of contained metal[b]	Per-cent of total	Thousands of tons of contained metal	Per-cent of total	Thousands of tons of contained metal	Per-cent of total	Thousands of tons of contained metal	Per-cent of total
Developed Countries	464	28	1127	19	3557	27	7344	37
Australia	1	0	15	0	1990	15	5979	30
Greece	15	1	177	3	458	4	657	3
U.S.	271	16	467	8	486	4	359	2
France	145	9	383	7	564	4	341	2
Other	32	2	87	2	58	1	8	0
Developing Countries	947	56	3769	64	7454	58	10376	52
Guinea	3	0	310	5	560	4	3061	15
Jamaica	0	0	1342	23	2761	21	2775	14
Surinam	409	24	691	12	1204	9	980	5
Brazil	4	0	24	0	102	1	830	4
Yugoslavia	47	3	236	4	483	4	722	4
Guyana	334	20	577	10	1015	8	702	3
India	14	1	78	1	275	2	348	2
Indonesia	106	6	79	1	245	2	250	1
Malaysia	0	0	150	3	228	2	184	1
Haiti	0	0	80	1	151	1	110	1
Ghana	3	0	159	3	352	3	52	0
Other	27	2	44	1	77	1	362	2
Socialist Countries	267	16	1026	17	1960	15	2350	12
U.S.S.R.	150	9	700	12	1300	10	1280	6
Hungary	116	7	238	4	404	3	590	3
China	0	0	70	1	100	1	340	2
Romania	1	0	18	0	155	1	140	1
TOTAL	1678	100	5922	100	12971	100	20070	100

Appendix Table 1a continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]The metal content of 1950 bauxite production is estimated for each country and country group by multiplying the ratio of the metal content of bauxite production in 1955 to the actual weight of that production times 1950 production in actual weight.

Source: United Nations Conference on Trade and Development, *The World Market for Bauxite: Characteristics and Trends: Statistical Annex* (1982); and *Metal Statistics* (various years).

Appendix Table 1b

Mine Production of Copper by Country and Country Group, Selected Years, 1950-1980[a]

Country and country group	1950 Thousands of tons of contained metal	1950 Percent of total	1960 Thousands of tons of contained metal	1960 Percent of total	1970 Thousands of tons of contained metal	1970 Percent of total	1980 Thousands of tons of contained metal	1980 Percent of total
Developed Countries	1203	48	1729	41	2723	43	2542	33
U.S.	825	33	980	23	1560	25	1168	15
Canada	240	10	398	9	610	10	708	9
Australia	15	1	111	3	158	3	232	3
S. Africa	34	1	48	1	149	2	212	3
Japan	39	2	89	2	120	2	53	1
Other	50	2	103	2	126	2	169	2
Developing Countries	1081	43	1885	44	2445	38	3462	44
Chile	363	14	532	13	692	11	1068	14
Zambia	298	12	576	14	684	11	596	8
Zaire	176	7	302	7	387	6	460	6
Peru	30	1	184	4	220	4	365	5
Philippines	10	0	44	1	160	3	305	4
Mexico	62	3	60	1	61	1	175	2
PNG[b]	0	0	0	0	0	0	147	2
Yugoslavia	43	2	33	1	91	1	117	1
Other	99	4	154	4	150	2	229	3
Socialist Countries	238	9	624	15	1211	19	1812	23
U.S.S.R.	218	9	500	12	925	15	1150	15
Poland	0	0	11	0	83	1	343	4
China	5	0	72	2	100	2	165	2
Bulgaria	0	0	11	0	43	1	62	1
Other	15	1	30	1	60	1	92	1
TOTAL	2522	100	4238	100	6379	100	7816	100

Notes:

[a]Figures may not sum to totals due to rounding.

[b]Papua New Guinea.

Source: Metal Statistics (various years).

Appendix Table 1c

Mine Production of Iron by Country and Country Group, Selected Years, 1950-1980[a]

	1950		1960		1970		1980	
Country and country group	Millions of tons of contained metal[b]	Percent of total	Millions of tons of contained metal	Percent of total	Millions of tons of contained metal	Percent of total	Millions of tons of contained metal	Percent of total
Developed Countries	81.8	69	120.1	48	174.7	41	198.3	38
Australia	1.4	1	2.9	1	32.8	8	60.1	12
U.S.	49.3	42	48.4	19	53.8	13	47.5	9
Canada	1.8	2	10.7	4	29.5	7	31.6	6
S. Africa	.7	1	1.8	1	4.7	1	18.9	4
Sweden	8.3	7	13.0	5	19.8	5	17.7	3
France	9.8	8	22.3	9	17.9	4	9.3	2
U. Kingdom	4.0	3	5.2	2	3.4	1	0.2	0
Other	6.5	6	15.8	6	12.8	3	13.0	3
Developing Countries	10.0	8	46.7	19	113.2	27	137.6	27
Brazil	1.4	1	3.4	1	24.7	6	62.2	12
India	1.9	2	10.3	4	19.4	5	25.2	5
Liberia	0.0	0	2.2	1	15.8	4	13.0	3
Venezuela	.1	0	11.9	5	13.1	3	9.4	2
Other	6.6	6	18.9	8	40.2	9	27.8	5
Socialist Countries	25.9	22	85.0	34	137.2	32	182.9	35
U.S.S.R.	23.0	20	63.9	25	106.1	25	136.4	26
China	2.2[c]	2[c]	16.5	7	24.2	6	40.3	8
Other	.7	1	4.6	2	6.9	2	6.2	1
TOTAL	117.7	100	251.9	100	425.1	100	518.8	100

Appendix Table 1c continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]The source for 1950 gives production in actual weight. These figures were converted to metal content using the ratio for each country and country group of the metal content of iron ore production in 1955 to the actual weight of that production times 1950 production in actual weight. The data on actual weight and metal content for 1955 production are from United Nations Conference on Trade and Development, *Statistics on Iron Ore* (1978).

[c]Chinese production figures shown for 1950 are for 1952.

Sources: American Metal Market, *Metal Statistics* (1952) for 1950 data; Wang (1975), p.7, for 1952 data on China; United Nations Conference on Trade and Development, *Proposed Establishment of an Annual Statistical Programme Relating to Iron Ore: Statistics on Iron Ore* (1981) for 1960, 1970, and 1980 data.

Appendix Table 1d

Mine Production of Nickel by Country and Country Group, Selected Years, 1950-1980[a]

Country and country Group	1950 Thousands of tons of contained metal	1950 Percent of total	1960 Thousands of tons of contained metal	1960 Percent of total	1970 Thousands of tons of contained metal	1970 Percent of total	1980 Thousands of tons of contained metal	1980 Percent of total
Developed Countries	114.2	77	211.0	62	346.6	52	324.2	43
Canada	112.2	76	194.6	57	277.5	42	194.9	26
Australia	0.0	0	0.0	0	29.8	4	69.8	9
S. Africa	0.8	0	2.9	1	11.6	2	25.7	3
Greece	0.0	0	0.0	0	8.6	1	14.0	2
U.S.	0.8	0	11.4	3	14.1	2	12.8	2
Other	0.4	0	2.1	1	5.0	1	7.0	1
Developing Countries	4.4	3	68.9	20	200.1	30	256.9	34
New Cal.[b]	4.3	3	53.5	16	138.5	21	86.3	12
Indonesia	0.0	0	0.0	0	10.8	2	40.5	5
Cuba	0.0	0	14.5	4	36.8	6	38.2	5
Philippines	0.0	0	0.0	0	0.0	0	34.9	5
Dom.Rep.[c]	0.0	0	0.0	0	0.0	0	15.5	2
Other	0.1	0	0.9	0	14.0	2	41.5	6
Socialist Countries	29.6	20	61.8	18	118.9	18	166.5	22
U.S.S.R.	29.0	20	58.0	17	110.0	17	143.0	19
Other	0.6	0	3.8	1	8.9	1	23.5	3
TOTAL	148.2	100	341.7	100	665.6	100	747.6	100

Notes:

[a]Figures may not sum to totals due to rounding.

[b]New Caledonia.

[c]Dominican Republic.

Source: Metal Statistics (various years).

Appendix Table 1e

Mine Production of Tin Country by Country Group, Selected Years, 1950-1980[a]

Country and country group	1950 Thousands of tons of contained metal	1950 Percent of total	1960 Thousands of tons of contained metal	1960 Percent of total	1970 Thousands of tons of contained metal	1970 Percent of total	1980 Thousands of tons of contained metal	1980 Percent of total
Developed Countries	3.8	2	5.6	3	13.3	6	17.0	7
Australia	1.9	1	2.2	1	8.8	4	10.4	4
U. Kingdom	0.9	1	1.2	1	1.7	1	3.0	1
S. Africa	0.7	0	1.3	1	2.0	1	2.4	1
Other	0.3	0	0.9	0	0.8	0	1.2	1
Developing Countries	160.7	91	132.7	70	170.8	79	182.2	78
Malaysia	58.5	33	52.8	28	73.8	34	61.4	26
Thailand	10.5	6	12.3	6	21.8	10	33.7	14
Indonesia	32.6	18	23.0	12	19.1	9	32.5	14
Bolivia	31.7	18	19.7	10	30.1	14	27.5	12
Brazil	b	b	b	b	4.3	2	6.8	3
Zaire	13.7	8	9.1	5	6.4	3	3.2	1
Nigeria	8.4	5	7.8	4	8.0	4	2.5	1
Burma	1.5	1	1.0	1	0.4	0	1.1	0
Other[c]	3.8	2	7.0	4	6.9	3	13.5	6
Socialist Countries	12.4	7	51.2	27	33.4	15	35.4	15
U.S.S.R.	2.0	1	20.0	11	10.0	5	17.0	7
China	10.1	6	30.0	16	22.0	10	16.0	7
Other	0.3	0	1.2	1	1.4	1	2.4	1
TOTAL	176.9	100	189.5	100	217.5	100	234.6	100

Notes:

[a]Figures may not sum to totals due to rounding.

[b]Data for Brazil for 1950 and 1960 included with other developing countries.

[c]This category may include a small amount of production from a few developed countries.

Source: Metal Statistics (various years).

Appendix Table 1f

Mine Production of Zinc by Country and Country Group, Selected Years, 1950-1980[a]

	1950		1960		1970		1980	
Country and country group	Thousands of tons of contained metal[b]	Per-cent of total	Thousands of tons of contained metal	Per-cent of total	Thousands of tons of contained metal	Per-cent of total	Thousands of tons of contained metal	Per-cent of total
Developed Countries	1414	64	1683	52	3181	57	3263	52
Canada	284	13	390	12	1253	23	1059	17
Australia	201	9	253	8	487	9	494	8
U.S.	565	26	395	12	485	9	368	6
Japan	52	2	157	5	280	5	238	4
Irish Rep.	b	b	b	b	97	2	229	4
Spain	64	3	85	3	98	2	179	3
Sweden	37	2	70	2	93	2	167	3
Germany	98	4	115	4	161	3	121	2
Italy	87	4	130	4	111	2	58	1
Other	26	1	88	3	116	2	350	6
Developing Countries	536	24	792	25	1125	20	1340	21
Peru	88	4	178	6	299	5	531	8
Mexico	224	10	271	8	266	5	238	4
Yugoslavia	38	2	56	2	101	2	94	2
Zaire	77	4	109	3	103	2	67	1
Bolivia	20	1	4	0	47	1	50	1
Other	89	4	174	5	309	6	360	6
Socialist Countries	260	12	746	23	1256	23	1645	26
U.S.S.R.	129	6	375	12	700	13	1000	16
Poland	114	5	144	5	187	3	217	3
China	0	0	60	2	100	2	150	2
N. Korea	c	c	75	2	130	2	130	2
Bulgaria	9	0	77	2	76	1	78	1
Other	8	0	15	0	63	1	70	1
TOTAL	2210	100	3221	100	5562	100	6248	100

Appendix Table 1f continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]Production for the Irish Republic included with other developed countries for 1950 and 1960.

[c]Production figures for North Korea are not available for 1950.

Source: Metal Statistics (various years).

Appendix Table 2a

Reserves of Bauxite by Country and Country Group, Selected Years, 1950-1980[a]

Country and country group	1950 Millions of tons of contained metal[c]	1950 Percent of total	1958[b] Millions of tons of contained metal[c]	1958[b] Percent of total	1970 Millions of tons of contained metal[c]	1970 Percent of total	1980 Millions of tons of contained metal[c]	1980 Percent of total
Developed Countries	50	12	173	22	1071	34	1090	23
Australia	4	1	121	16	1016	33	930	20
Greece	17	4	21	3	23	1	140	3
France	18	4	19	2	21	1	10	0
U.S.	11	3	12	2	11	0	10	0
Developing Countries	285	66	494	64	1864	60	3410	73
Guinea	2	0	155	20	1097	35	1240	27
Brazil	d	d	d	d	276[d]	9[d]	510	11
Jamaica	80	19	125	16	203	7	420	9
Guyana	20	5	22	3	24	1	170	4
Surinam	15	3	53	7	177	6	140	3
Other	168	39	139	18	87	3	920[f]	20[f]
Socialist Countries	97	22	105	14	178	6	150	3
U.S.S.R.[e]	9	2	25	3	76	2	50	1
Other	88	20	80	10	102	3	100	2
TOTAL	432	100	772	100	3113	100	4660	100

Appendix Table 2a continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]The closest year to 1960 for which bauxite reserves are available is 1958.

[c]Metal content is estimated for 1950, 1958, and 1970 on the basis of alumina grade and the assumption that 50 percent of alumina is aluminum metal. Alumina grades for 1958 are estimated on the basis of 1950 and 1970 grades. The figures for 1980 are estimates of recoverable aluminum, and hence not totally comparable to those for earlier years.

[d]Brazilian reserves for 1950 and 1960 are included with other developing countries. The country's 1970 reserves were estimated by averaging its reported reserves in 1965 and 1975.

[e]U.S.S.R. reserves include low grade ore that would not be counted as reserves in most countries.

[f]The 1980 figures for other developing countries include 60 million tons of reserves whose country of origin is unspecified.

Sources: Dorr (1975); U.S. Bureau of Mines, *Materials Survey: Bauxite* (1953); U.S. Bureau of Mines, *Mineral Facts and Problems* (various years); U.S. Department of the Interior, *First Annual Report of the Secretary of the Interior Under the Mining Policy Act of 1970* (1972); U.S. Bureau of Mines, *Mineral Commodity Summaries* (various years); and United Nations Conference on Trade and Development, *The World Market for Bauxite: Statistical Annex* (1982).

Appendix Table 2b

Reserves of Copper by Country and Country Groups, Selected Years, 1950-1980[a]

Country and country group	1950 Millions of tons of contained metal	1950 Percent of total	1960 Millions of tons of contained metal	1960 Percent of total	1970 Millions of tons of contained metal	1970 Percent of total	1980[b] Millions of tons of contained metal	1980[b] Percent of total
Developed Countries	45.2	35	42.2	22	129.2	41	187.0	34
U.S.	38.0	30	29.5	15	73.5	23	101.0	19
Canada	3.8	3	7.6	4	27.2	8	35.0	6
Australia	.7	1	1.1	1	5.1[d]	2	9.0	2
Other	2.7[c]	2	4.0	2	24.1[e]	8	42.0	8
Developing Countries	67.4	52	104.9	54	142.2	44	290.0	53
Chile	24.0	19	41.7	22	50.8	16	107.0	20
Zambia	19.0	15	22.7	12	24.5	8	37.0	7
Peru	10.0	8	11.3	6	20.0	6	35.0	6
Zaire	8.0	6	18.1	9	18.1	6	26.0	5
Philippines	.3	0	.9	0	10.5[d]	3	20.0	4
Other	6.1[c]	5	10.2	5	18.3[e]	6	65.0[e]	12
Socialist Countries	16.1	13	45.6	24	48.0	15	66.0	12
U.S.S.R.	10.8	8	31.8	17	31.8	10	40.0	7
Poland	3.4[c]	3	3.5	2	9.3[d]	3	14.0	3
Other	1.9[c]	1	10.3	5	6.9	2	12.0	2
TOTAL	128.7	100	192.7	100	320.1	100	543.0	100

Appendix Table 2b continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]The source of the 1980 reserve figures, U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980), indicates that they are for the reserve base, which it defines as the "in-place part of the demonstrated (measured plus indicated) resource from which reserves are estimated. It encompasses those parts of the resources that are likely to be economically available within a long-term planning frame. The reserve base corresponds closely to what in earlier years the *Mineral Commodity Summaries* called reserves.

[c]Reserves for 1950 for Poland, other developed countries, other developing countries, and other socialist countries were estimated by interpolating their 1945 and 1960 reserve figures.

[d]Reserves for 1970 for Australia, the Philippines, and Poland were estimated by interpolating their 1960 and 1980 reserves.

[e]Some reserves for 1970 and 1980 were classified as belonging to other countries without any indication as to whether these were developed or developing countries. The division of these reserves between the two country groups was made on the basis of the relative mine production of the developed and developing countries whose reserves were not separately identified.

Sources: U.S. Federal Trade Commission, *Report on the Copper Industry* (1947); U.S. Bureau of Mines, *Materials Survey: Copper* (1952); A.D. McMahon, *Copper: A Materials Survey* (1965); U.S. Department of the Interior, *First Annual Report of the Secretary of the Interior Under the Mining and Minerals Policy Act of 1970* (1972); Whitney (1976); U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980).

Appendix Table 2c

Reserves of Iron Ore by Country and Country Group, Selected Years, 1950-1980[a]

Country and country group	1950 Billions of tons of contained metal	1950 Percent of total[c]	1954 Billions of tons of contained metal	1954 Percent of total[c]	1967 Billions of tons of contained metal	1967 Percent of total[c]	1980[b] Billions of tons of contained metal	1980[b] Percent of total[c]
Developed Countries	8.9	34	12.6	31	30.9	32	33.3	35
Canada	.9	3	1.5	4	10.6	11	10.9	12
Australia	.1	0	.3	1	9.2	10	10.7	11
U.S.	1.7	6	3.0	7	3.3	3	5.3	6
France	2.5	9	2.1	5	2.4	2	1.6	2
Sweden	1.4	5	1.4	3	1.8	2	2.0	2
S. Africa	1.3	5	2.4	6	1.1	1	1.1	1
Other	1.0	4	1.9	5	2.5	3	1.7[d]	2
Developing Countries	14.7	55	23.6	58	24.9	26	29.9	32
Brazil	4.1	15	7.6	19	14.1	15	16.3	17
India	5.6	21	10.5	25	3.9	4	5.6	6
Venezuela	.2	1	1.3	3	1.2	1	1.3	1
Liberia	0.0	0	.1	0	.5	1	.6	1
Other	4.8	18	4.1	10	5.2	5	6.1[d]	6
Socialist Countries	2.9	11	4.4	11	40.8	42	31.5	33
U.S.S.R.	2.0	8	3.1	8	38.5	40	28.1	30
China	.8	3	1.1	3	2.1	2	2.7	3
Other	.1	0	.2	0	.2	0	.7	1
TOTAL	26.5	100	40.6	100	96.6	100	94.7	100

Appendix Table 2c continued

Notes:

[a]Reserves for 1960 and 1970 are not available. The closest available years are 1954 and 1967.

[b]The source of the 1980 reserve figures, U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980), indicates that they are for the reserve base, which it defines as the "in-place part of the demonstrated (measure plus indicated) resource from which reserves are estimated. It encompasses those parts of the resources that are likely to be economically available within a long-term planning frame." The reserve base corresponds closely to what in earlier years the *Mineral Commodity Summaries* called reserves.

[c]Figures may not sum to totals due to rounding.

[d]Reserves for 1980 were not separately identified for South Africa, other developed countries, and other developing countries. The division of reserves between the other developed and other developing countries was made on the basis of their relative production of iron ore. The reserves of South Africa were assumed to be the same in 1980 as in 1967. These reserves--1.1 billion tons--were then taken from the estimated reserves for other developed countries.

Sources: U.N., *World Iron Ore Resources and Their Utilization* (1950); U.N., *Survey of World Iron Ore Resources* (1955); U.N., *Survey of World Iron Ore Resources* (1970); U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980).

Appendix Table 2d

Reserves of Nickel by Country and Country Group, Selected Years, 1950-1980[a,b]

	1950		1970		1980	
Country and country group	Millions of tons of contained metal	Per-cent of total	Millions of tons of contained metal	Per-cent of total	Millions of tons of contained metal	Per-cent of total
Developed Countries	4.6	14	11.7	18	14.2	26
Canada	4.1	12	9.1	14	7.9	15
Australia	.0	0	.9	1	5.1	9
U.S.	.5	2	.2	0	.3	1
Other	.0	0	1.5	2	1.0[c]	2
Developing Countries	28.5	86	45.2	68	32.6	60
New Caledonia	1.0	3	15.0	23	13.6	25
Indonesia	.5	2	7.3	11	7.1	13
Philippines	4.0	12	4.1	6	5.2	10
Cuba	22.1	67	16.3	25	3.1	6
Dominican Rep.	.0	0	0.7	1	1.0	2
Other	.9	3	1.8	3	2.6[c]	5
Socialist Countries	.1	0	9.2	14	7.3	13
U.S.S.R.	.1	0	9.1	14	7.3	13
Other	.0	0	.1	0	.0	0
TOTAL	33.2	100	66.1	100	54.1	100

Notes:

[a]Data on nickel reserves around 1960 not available.

[b]Figures may not sum to totals due to rounding.

[c]Reserves for Africa, which were not broken down by country, were divided between developed countries (South Africa) and developing countries on the basis of their relative 1980 mine production of nickel.

Sources: Hubbard (1975); U.S. Bureau of Mines, *1950 Materials Survey: Nickel* (1952); U.S. Bureau of Mines, *Mineral Facts and Problems* (various editions).

Appendix Table 2e

Reserves of Tin by Country and Country Group, Seleted Years, 1950-1980[a]

Country and country group	1950[b] Thousands of tons of contained metal	1950[b] Percent of total	1960 Thousands of tons of contained metal	1960 Percent of total	1968[c] Thousands of tons of contained metal	1968[c] Percent of total	1980[d] Thousands of tons of contained metal	1980[d] Percent of total
Developed Countries	141	2	140	3	146	3	640	7
Australia	35	1	43	1	82	2	330	3
U.Kingdom	40[f]	1	43	1	38	1	260	3
Other	66[e]	1	54[e]	1	26[e]	1	50[e]	1
Developing Countries	4934	73	3964	75	3534	80	6560	68
Indonesia	1000	15	567	11	559	13	1550	16
Malaysia	1500	22	1016	19	610	14	1200	12
Thailand	800	12	1106	21	1425	32	1200	12
Bolivia	500	7	746[g]	14	493	11	980	10
Burma	300	4	181[f]	3	61	1	500	5
Brazil	0	0	0	0	102	2	400	4
Nigeria	250	4	91	2	87	2	280	3
Zaire	500	7	207	4	157	4	200	2
Other	84[e]	1	50[e]	1	40[e]	1	250[e]	3
Socialist Countries	1650	25	1186	22	721	16	2500	25
China	1500	22	1004	19	508	11	1500	15
U.S.S.R.	150[f]	2	182	3	213	5	1000	10
TOTAL	6725	100	5290	100	4401	100	9700	100

Appendix Table 2e continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]The source for 1950 was at times unclear whether reserve figures were in metric or long tons. In such cases, metric tons were assumed.

[c]The closest year to 1970 for which reserves are available is 1968.

[d]The source of the 1980 reserve figures, U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980), indicates that they are for the reserve base, which it defines as the "in-place part of the demonstrated (measured plus indicated) resource from which reserves are estimated. It encompasses those parts of the resources that are likely to be economically available within a long-term planning frame." The reserve base corresponds closely to what in earlier years the *Mineral Commodity Summaries* called reserves.

[e]Reserves for other developed and other developing countries were not separately identified. The division of reserves between these two groups was made on the basis of their relative mine production of tin.

[f]These figures were estimated by taking a multiple of production, by interpolation, or by other means.

[g]The reserve figure for Bolivia shown for 1960 is actually for 1961.

Source: President's Materials Policy Commission, *Resources for Freedom* (1952); Robertson (1965); U.S. Bureau of Mines, *Mineral Facts and Problems* (1970); and U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980).

Appendix Table 2f

Reserves of Zinc by Country and Country Group, Selected Years, 1950-1980[a]

	1950		1957[b]		1970		1980[c]	
Country and country group	Millions of tons of contained metal	Per-cent of total	Millions of tons of contained metal	Per-cent of total	Millions of tons of contained metal	Per-cent of total	Millions of tons of contained metal	Per-cent of total
Developed Countries	35.9	56	49.9	65	78.6	67	171.0	71
Canada	4.5[d]	7	15.1	20	30.8	26	62.0	26
U.S.	7.7	12	12.2	16	27.2	23	48.0	20
Australia	12.7	20	10.0	13	9.1	8	24.0	10
Other	11.0[f,g]	17	12.6[f,g]	16	11.5[h]	10	37.0[h]	15
Developing Countries	18.2	28	15.3	20	20.2	17	45.0	19
Peru	e	e	e	e	e	e	7.0	3
Mexico	3.5[d]	5	6.0	8	3.6	3	3.0	1
Other	14.7[f,g]	23	9.3[f,g]	12	16.6[h]	14	35.0[h]	15
Socialist Countries	10.2[g]	16	11.2[g]	15	18.1	15	24.0	10
TOTAL	64.3	100	76.4	100	116.9	100	240.0	100

Appendix Table 2f continued

Notes:

[a]Figures may not sum to totals due to rounding.

[b]The closest year to 1960 for which reserves are available is 1957.

[c]The source of the 1980 reserve figure, U.S. Bureau of Mines, *Mineral Commodity Summaries* (1980), indicates that they are for the reserve base, which it defines as the "in-place part of the demonstrated (measure plus indicated) resource from from which reserves are estimated. It encompasses those parts of the resources that are likely to be economically available within a long-term planning frame." The reserve base corresponds closely to what in earlier years the *Mineral Commodity Summaries* called reserves.

[d]Reserves for Canada and Mexico for 1950 are estimates based on their combined reserves.

[e]Reserves for Peru for 1950, 1960, and 1970 are included with other developing countries.

[f]Reserves for Yugoslavia for 1950 and 1957 are included with other developed countries, rather than other developing countries.

[g]Reserves for Asia were not broken down by country in 1950 and 1957. In calculating the reserves held by other developed countries, other developing countries, and the socialist countries, 90 percent of the 1950 reserves for Asia were assumed to be in Japan, 5 percent in China, and 5 percent in developing countries. For 1957, 65 percent of Asian reserves were assumed to be in Japan, 30 percent in China, and 5 percent in developing countries.

[h]Reserves for other developed and other developing countries were not separately identified in 1970 and 1980. The division of reserves between these two groups was made on the basis of their relative mine production of zinc.

Sources: U.S. Bureau of Mines, *Materials Survey: Zinc* (1950); U.S. Bureau of Mines, *Mineral Facts and Problems* (1960); U.S. Department of the Interior, *First Annual Report of the Secretary of the Interior Under the Mining Minerals Policy Act of 1970* (1972); U.S. Bureau of Mines, *Mineral Commodities Summaries* (1980).