NOT FOR QUOTATION
WITHOUT PERMISSION
OF THE AUTHOR

THE IMPACT OF SEABED MINING: A QUALITATIVE ANALYSIS

John E.Tilton

April 1983
WP-83-45

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
2361 Laxenburg, Austria

THE AUTHOR

John E. Tilton, currently a Research Scholar at IIASA, is on leave from the Pennsylvania State University, where he is a Professor of Mineral Economics. His work at IIASA mainly focuses on the economics of mineral trade and markets.

FOREWORD

Fear that the world may soon deplete its available resources of copper, nickel, and other mineral commodities arises from time to time. The most recent wave of concern appeared in the early 1970s as a result of rather severe mineral shortages and other developments at that time. Over the intervening years, however, research conducted at IIASA and elsewhere has concluded that mineral depletion is not a pressing global problem for at least the foreseeable future--the rest of this century and well into the next. While the depletion of high grade mines may require the use of poorer quality and higher cost deposits, new technology tends to offset the adverse effects of depletion by reducing the costs of exploration, mining and processing, and by increasing the range of substitute materials.

This research, coupled with falling mineral prices and depressed market conditions in recent years, has led some to conclude that non-fuel minerals pose little or no threat to the future welfare of mankind. Others, however, are more circumspect, aware that adequate mineral resources alone are not enough. Serious shortages can still occur, and last for several years, if investment in new mines and processing facilities is insufficient, if the demand for minerals surges in response to booms in the business cycle, or if mineral trade is interrupted by embargoes, civil disruptions, and other political events. In addition, new sources of mineral supplies, such as seabed mining, and the instability of mineral markets caused by the business cycle can seriously threaten families, communities, and even countries that depend on mining and mineral processing for income and employment. It was concerns such as these that led IIASA to initiate, in July 1982, a research effort on Mineral Trade and Markets, as a project of the Patterns of Economic Structural Change and

Industrial Adjustment Program.

This paper, in its present form was originally prepared under contract with the United Nations and was presented at the expert group meeting on the Impact of Seabed Minerals on the World Economy which was organized by the United Nations Department of International Economic and Social Affairs, Ocean Economics and Technology Branch and convened at the United Nations Headquarters in New York on 20 January 1983.

John E. Tilton
Research Leader
Mineral Trade and Markets Project

ABSTRACT

This paper considers the future effects of seabed mining on the cobalt, copper, manganese, and nickel industries, and the implications for producing and consuming states. The analysis is qualitative, or conceptual, in nature. While no effort is made to actually measure or quantify the impacts of seabed mining, important variables that one would have to consider in making such measurements are identified.

While deep-sea mining holds the promise of potentially less expensive sources of minerals, it also raises the specter of dislocation and decline for land-based producers, many of whom are located in the developing countries. There is widespread concern that unless seabed mining is regulated, most of the benefits flowing from this "common heritage of mankind" will go to the developed countries that have both the technology to exploit these minerals and the capacity to consume the output.

Despite the study's fairly narrow scope, two general conclusions emerge. First, measuring the future impacts of seabed mining is an extremely complicated and difficult endeavor. There is much disagreement about the relative costs of seabed and land-based production.How scientific breakthroughs and other technological developments will alter future costs is simply unknown,and to some extent unknowable. Moreover, relative costs alone will not be the only determinant of the future level of seabed mining. Some countries may support such production to lessen their dependence on foreign producers. Distressed land-based producers may receive assistance from their own governments and protection in the form of constraints on seabed production, negotiated through international agreements. Thus production may be influenced as much by political decisions as by economic considerations. Even if the future level of seabed mining could be ascertained, its impact would be difficult

to assess *ex ante*. Such assessments require knowledge of long-run supply and demand curves that goes beyond observed historical price and output equilibria. Nor is it clear how these curves will shift over time in response to resource depletion, technological progress, the introduction of new materials, changes in mineral policies, and other factors.

Second, the potential impacts of seabed mining appear to vary and to be less bounded than is often presumed. For example, the first commercial mining of seabed nodules is widely anticipated during the 1990s and several consortia are expected to be in operation by the end of the century. Yet the necessary technology, particularly on the scale required, has not yet been proven. Further, it is not clear whether the requisite policies to protect investments are in place. These uncertainties raise the possibility that seabed mining could suffer a fate similar to that of oil shale,where for years commercial production appeared imminent but the goal remains elusive. Moreover,the impacts of seabed mining are not fully appreciated as is evident by the argument that seabed mining could not force existing land-based mines to close. The rationale for this position overlooks the potential influence of new technology on relative costs of both seabed and land-based mining and ignores the coproduct nature of seabed operations and the substantial effect of. even limited production on the cobalt market and perhaps on the manganese market.

CONTENTS

THE IMPACT OF SEABED MINING: A QUALITATIVE ANALYSIS

John E.Tilton

INTRODUCTION

Twenty years ago seabed nodules were a scientific curiosity of little public interest. Today, thanks to a number of technological advances, they represent a major potential source of cobalt, copper, manganese, and nickel, and several consortia of private firms and public enterprises are seriously contemplating their commercial exploitation.

Although actual production is still a number of years off, a lively debate has already arisen over appropriate measures to assure the timely and efficient development of seabed minerals, to minimize the adverse effects on land-based mineral producers, and to promote a wide and equitable distribution of the resulting benefits. While deep sea mining offers the promise of a major new and potentially less expensive source of minerals, it also raises the specter of dislocation and decline for land-based producers, many of which are developing countries. In addition, there is widespread concern that, unless seabed mining is closely regulated, most of the benefits flowing from this "common heritage of mankind" will go to the developed industrialized countries. They possess the necessary technology to exploit seabed minerals, and with their huge appetite for all raw materials have the capacity to consume the resulting output.

This paper considers the future effects of seabed mining on the cobalt, copper, manganese, and nickel industries, and the implications for producing and consuming states. The analysis is qualitative, or conceptual, in nature. While no effort is made to actually measure or quantify the impacts of seabed mining, important variables that one would have to consider in making such measurements are identified. The focus is on three concerns, each of which encompasses a set of questions about the future consequences of seabed mining. The first is the effect on future production costs. The depletion of higher grade, more readily accessible, and easier-to-process deposits exerts, over time, upward pressure on the costs of producing minerals. In the past, this upward pressure has been largely or completely offset by the cost reducing effects of new technology (Barnett and Morse, 1963; Barnett, 1979). On a number of occasions, technology has opened up entirely new sources of supply, as the successful extraction of copper from porphyry deposits and iron from taconite so clearly illustrates. Such developments help hold at bay the long-run threat of resource exhaustion.

Do seabed nodules offer a similar opportunity? Can they keep the costs and prices of cobalt, copper, manganese, and nickel from rising over the long run as fast as they otherwise would? Are they potentially a lower cost source of supply than present land-based deposits? These questions are important for producers as well as consumers. Persistent price increases over the long run force consumers to search for alternative materials, and so adversely affect the markets of producers.

The second effect of interest concerns the location of future mining activity. Will seabed operations cause land-based production to decline? In particular, will they reduce output in the developing countries, and thus the contribution of mining to the much needed economic growth of these states? How will seabed mining ultimately affect the diversity of supply sources? Will it increase or decrease the vulnerability of consuming countries to supply interruptions? Will producing firms, governments, and international bodies find it easier or more difficult to exercise monopoly power, to form producer cartels, or in other ways to control mineral markets?

The third concern involves the welfare implications of seabed mining for consuming and producing countries. In particular, how will the benefits and costs be distributed? Will most of the benefits go to the developed countries? Will land-based producing countries, particularly those that are developing, suffer severely? Will efforts to help the land-based producers assist the developed countries more than the developing countries?

In examining these issues, one needs to define an appropriate time period and a base case which shows how production costs, the location of mining, and the distribution of benefits would evolve over the period of interest in the absence of seabed mining. Since commercial production of seabed nodules may not begin before the mid 1990s, the focus here is on the 25 year period from 1995 through 2020.

Recent trends in the cobalt, copper, manganese, and nickel markets are assessed in the next section, along with their implications for the evolution of these markets over the 1995-2020 period. This sets the stage for the following section to consider conceptually the consequences of seabed mining. The final section then describes the research needed if the anticipated consequences are eventually to be measured and their impacts fully assessed.

RECENT TRENDS

This section investigates recent trends in the prices and production costs, the location of mining activity, and the distribution of the benefits from trade in the principal mineral commodities contained in seabed nodules.

Prices and Production Costs

Table 1 indicates the average annual real prices in 1978 dollars for cobalt, copper, manganese, and nickel over the 25 year period 1954-79 in the United States. Except for manganese, where all prices are negotiated, the prices shown are producer prices, as changes in these prices parallel movements in long-run costs more closely than prices determined on the London Metal Exchange, COMEX, or other competitive markets.

The most striking surge in price reported in Table 1 occurs for cobalt in 1978-79, and reflects the disruption of supplies from Zaire that occurred in 1978 when rebels based in Angola invaded the Shaba Province and overran the country's principal mining areas. The expansion of output elsewhere and the substitution of alternative materials stimulated by the unusually high price of cobalt, coupled with the resumption of supplies from Zaire and generally depressed market conditions, have since caused the real price of cobalt to drop sharply. Aside from this rather dramatic perturbation, the price of cobalt fell and then rose modestly over the period examined.

Copper prices display no pronounced trend, but rather appear to move up and down in response to short-run market conditions. Manganese shows a secular decline in prices through the early 1970s that recent years have only partially reversed. In contrast, nickel has enjoyed a modest but fairly persistent increase in price.

While the figures of Table 1 more or less reflect changes over time in the prices that consumers have had to pay,[1] the extent to which they indicate trends in the long-run costs of marginal producers is somewhat less certain. It is true that in competitive industries where no serious

[1]As the cobalt, copper, manganese, and nickel markets in the United States are closely tied to those abroad, U.S. prices tend to parallel the prices elsewhere. Still, there are at times differences between the prices paid by consumers in the United States and other countries. Moreover, the figures shown in Table 1 may not precisely reflect the average prices actually paid by U.S. consumers for a number of reasons. For example, some cobalt, copper, and nickel is purchased from COMEX, from metal dealers or other sources that do not adhere to the producer price. In addition, even the producers themselves at times offer open or secret discounts from their quoted price.

Table 1. Average Annual Real Prices for Cobalt, Copper, Manganese, and Nickel in the United States, 1954-79.

Year	Prices in (1978) Dollars			
	Cobalt (per pound)	Copper (per pound)	Manganese (per long-ton unit)	Nickel (per pound)
1954	6.62	.75	2.46	1.64
1955	6.49	.93	2.60	1.60
1956	6.24	1.03	3.50	1.78
1957	4.74	.70	3.68	1.72
1958	4.60	.61	2.78	1.70
1959	3.98	.69	2.21	1.67
1960	3.41	.71	2.08	1.64
1961	3.29	.66	2.06	1.78
1962	3.23	.66	1.96	1.70
1963	3.19	.65	1.72	1.68
1964	3.14	.68	1.44	1.65
1965	3.31	.72	1.49	1.59
1966	3.27	.73	1.51	1.68
1967	3.56	.74	1.29	1.81
1968	3.41	.78	1.10	1.90
1969	3.31	.84	.88	2.24
1970	3.66	.97	.90	2.13
1971	3.48	.82	.95	2.11
1972	3.72	.78	.91	2.13
1973	4.31	.86	.93	2.20
1974	4.53	1.01	1.18	2.28
1975	4.76	.77	1.65	2.43
1976	5.05	.79	1.65	2.50
1977	5.99	.72	1.59	2.33
1978	11.53	.67	1.40	2.08
1979	22.59	.86	1.29	2.21

Sources: U.S. Bureau of Mines, Cobalt (1980); U.S. Bureau of Mines, Copper (1980); U.S. Bureau of Mines, Manganese (1980); U.S. Bureau of Mines, Nickel (1980); U.S. Bureau of Mines, Cobalt-1977 (1977); U.S. Bureau of Mines, Copper-1977 (1977); U.S. Bureau of Mines, Manganese-1977 (1977); U.S. Bureau of Mines, Nickel-1977 (1977).

obstacles prevent firms from entering or leaving, one would expect prices to fluctuate around long-term costs, where the latter include an appropriate rate of return on equity capital. If prices were below such costs, firms would leave the industry and capacity would decline. If prices were above costs, investors would divert more of their available funds into the industry, and expand capacity. Eventually such behavior should push prices back toward costs. Herfindahl (1959) in his well-known study of the copper industry employed this rationale to justify the use of prices to estimate long-run trends in the cost of producing copper.

In monopolistic or oligopolistic industries, prices may be maintained above production costs over the long term, allowing firms to earn excess profits. Still, there are reasons to believe such firms will adjust their prices in response to changes in long-run costs. Thus, changes in price may reflect shifts in costs, even though price levels may be maintained above costs.

Despite such considerations, the price trends shown in Table 1 may not accurately parallel long-run cost trends. The mining and processing of metals are energy and capital intensive. Consequently, the sharp rise in the prices of energy, plants, and equipment during the 1970s exerted considerable upward pressure on production costs. Stricter regulations in the developed countries governing pollution control along with higher interest rates worldwide accentuated this pressure.

While Table 1 shows the prices for all four metals examined tended to rise modestly during the 1970s, for two reasons producers have probably not yet been able to pass on in the form of higher prices the full increase in long-run production costs. First, since the worldwide boom of 1973-74, the economies of the major industrialized countries have been relatively depressed, due largely to high interest rates and other macro-economic policies pursued to curb inflation and to maintain balance of payments. Since metals are largely consumed in the industrialized countries, and in particular in those economic sectors--capital equipment, construction, transportation, and consumer durables--whose output is highly sensitive to overall fluctuations in the business cycle, the demand for most metals has suffered for nearly a decade. It is difficult for producers to raise prices when markets are depressed.

Second, the cobalt, copper, manganese, and nickel industries have all experienced considerable structural change over the last several decades. The host governments of some producing countries have acquired control over significant production capacity from multinational mining corporations. For this and other reasons, these industries have grown more competitive. Under such conditions, prices can decline relative to long-run cost for prolonged periods.

Thus, while new technology could conceivably have offset the upward pressure on production costs resulting from higher energy, capital, and pollution control costs and in the process prevented metal prices from rising sharply during the 1970s, a more likely explanation of the modest price increases is that structural adjustment and market conditions have simply not yet permitted producers to pass on fully their increased costs to consumers. This explanation is consistent with the findings of available feasibility studies for major new mineral projects, which indicate that considerably higher metal prices are needed to make the expected returns attractive to investors. In copper, for example, analyses of the

Cerro Colorado deposit in Panama and other major undeveloped porphyry bodies indicate that a price of between 1.50 and 2.00 dollars per pound of copper is needed to justify their development. If such new sources of supply will eventually have to be developed to satisfy future demand, as is widely assumed, this implies that the price of copper will have to rise appreciably in real terms to cover the upward shift in costs over the last decade.

Location of Mining

Mine production of cobalt, copper, manganese, and nickel in the major producing countries and groups of countries is shown in Tables 2a-d for the years 1950 and 1980, along with the distribution of reserves in the latter year. These tables reveal several interesting aspects of the shift in mining activity over the last three decades.

First, despite the widespread belief that the developed industrialized countries are becoming increasingly dependent on the developing countries for essential mineral commodities, the share of world output coming from the developing countries has not appreciably increased for most of the metals contained in seabed nodules. The notable exception is nickel, where the rise of Cuba, Indonesia, and the Philippines as producers and the expansion of output in New Caledonia have helped the developing countries capture 34% of the market compared to a modest 3% in 1950. While the share of the developed market economy countries has fallen from 77% to 44%, they still produce together more nickel than either of the other groups. With cobalt and manganese, the developing countries have actually seen their share of world output decline over the last thirty

Table 2a. Cobalt Mine Production and Reserves by Country, 1950 and 1980.

	Mine Production				Reserves	
	1950		1980		1980	
	Thousands of Tons, Cobalt Content	Percent	Thousands of Tons, Cobalt Content	Percent	Thousands of Tons, Cobalt Content[b]	Percent
Developing Countries	6.2	86	21.6	72	2070	86
Morocco	.4	5	1.0	3	45	2
Philippines	a	-	1.3	4	180	8
Zaire	5.1	71	15.5	52	1180	49
Zambia	.7	10	3.3	11	365	15
Others	a	-	.5	2	300	12
Developed Market Economy Countries	1.0	14	4.5	15	115	5
Australia	a	-	1.6	5	45	2
Canada	.3	4	1.6	5	25	1
Finland	a	-	1.3	5	20	1
Others	.7	10	a	-	25	1
Socialist Countries	a	-	3.8	13	225	9
Total	7.2	100	29.9	100	2410	100

Notes: [a]Production was under .25 tons.

[b]Reserve figures were converted from pounds to metric tons and then rounded to the nearest five thousand tons.

Sources: Charles River Associates (1969), Table 2-1; U.S. Bureau of Mines, Mineral Commodity Summaries (1982), p. 37; and U.S. Bureau of Mines, Cobalt (1980), Table 5.

Table 2b. Copper Mine Production and Reserves by Country, 1950 and 1980.

	Mine Production				Reserves	
	1950		1980		1980	
	Thousands of Tons, Copper Content	Percent	Thousands of Tons, Copper Content	Percent	Millions of Tons, Copper Content	Percent
Developing Countries	1063	42	3464	44	279	55
Chile	363	14	1068	14	97	19
Peru	30	1	365	5	32	6
Philippines	10	-	305	4	18	4
Zaire	176	7	460	6	30	6
Zambia	298	12	596	7	34	7
Others	186	8	670	8	68[a]	13
Developed Market Economy Countries	1224	48	2541	33	166	33
Australia	15	1	232	3	16	3
Canada	240	9	708	9	32	6
South Africa	34	1	212	3	5	1
United States	825	33	1168	15	90	18
Others	110	4	221	3	23[a]	5
Socialist Countries	238	10	1812	23	60	12
Poland	-		343	4	13	3
USSR	218	9	1150	15	36	7
Others	20	1	319	4	11	2
Total	2525	100	7817	100	505	100

Note: [a]Reserves for unidentified nonsocialist countries were allocated to other developing countries and other developed market economy countries in proportion to the relative production of these two groups of countries in 1980.

Sources: Metallgesellschaft (1958), pp. 13-14; Metallgesellschaft (1981), pp. 29-30; and U.S. Bureau of Mines, Mineral Commodity Summaries (1982), p. 41.

Table 2c. Manganese Mine Production and Reserves by Country, 1950 and 1980.

	Mine Production				Reserves	
	1950		1980		1980	
	Thousands of Tons, Actual Weight	Percent	Thousands of Tons, Actual Weight	Percent	Millions of Tons, Actual Weight[c]	Percent
Developing Countries	2504	33	7074	26	330	7
Brazil	195	3	2177	8	85	2
Gabon	-	-	2146	8	145	3
India	919	12	1646	6	45	1
Others	1390	18	1105[b]	4	55[d]	1
Developed Market Economy Countries	1164	15	7656	29	2295	47
Australia	15	-	1961	8	300	6
South Africa	792	10	5695	21	1995	41
Others	357	5	b	-	d	-
Socialist Countries	3954[a]	52	11967	45	2245	46
China	a	-	1588	6	45	1
USSR	3861	51	10251	38	2175	45
Others	93[a]	1	128	1	25	-
Total	7622[a]	100	26697	100	4870	100

Notes: [a]Figures for 1950 exclude production in the socialist countries of Asia.

[b]Production shown for others under developing countries for 1980 includes minor amounts of production from other developed countries.

[c]Reserve figures were converted from short to metric tons and then rounded to the nearest five million tons.

[d]Reserves shown for others under developing countries may include minor amounts of reserves located in other developed countries.

Sources: UNCTAD, Considerations of International Measures on Management (1977), Table Ib; and U.S. Bureau of Mines, Mineral Commodity Summaries (1982). p. 95.

Table 2d. Nickel Mine Production and Reserves by Country, 1950 and 1980.

	Mine Production				Reserves	
	1950		1980		1980	
	Thousands of Tons, Nickel Content	Percent	Thousands of Tons, Nickel Content	Percent	Millions of Tons, Nickel Content	Percent
Developing Countries	4	3	256	34	40.4	63
Cuba	-	-	38	5	3.4	5
Indonesia	-	-	40	5	8.8	14
New Caledonia	4	3	86	11	13.5	21
Philippines	-	-	35	5	6.5	10
Others	-	-	57	8	8.2	13
Developed Market Economy Countries	114	77	325	44	13.9	22
Australia	-	-	70	9	2.5	4
Canada	112	75	195	26	7.6	12
South Africa	1	1	26	4	.8	1
Others	1	1	34	5	3.0	5
Socialist Countries	30	20	167	22	9.9	15
USSR	29	19	143	19	9.0	14
Others	1	1	24	3	.9	1
Total	148	100	748	100	64.2	100

Sources: Metallgesellschaft (1958), p. 31; Metallgesellschaft (1981), p. 55; and U.N. Department of Technical Co-operation for Development (1980), Table 3.

years, though as a group they still account for nearly three-fourths of world cobalt production.

Second, the developed countries have maintained and in some cases increased their share of world mine output, not because the United States and other major industrialized countries have expanded their domestic production, but rather because Australia, Canada, and South Africa have become increasingly important mineral exporters. This suggests that the developed industrialized countries are relying more on imports for their mineral needs, even though their dependence on imports from developing countries have remained stable or even declined.

Third, in 1950 Zaire was the principal producer of cobalt, the United States of copper, the Soviet Union of manganese, and Canada of nickel. Over the intervening years, the market shares of all of these dominant producers have fallen greatly. The most striking example is the drop in Canadian nickel output from 75% to 26% of the world total. Despite these declines, the major producers of thirty years ago are still major producers today. In contrast, even more dramatic shifts in comparative advantage are found in the location of mining for other mineral commodities. In bauxite, for example, the major producer in 1950, Surinam, saw its output over the years surpassed first by Jamaica, and then by Australia and Guinea.

Fourth, over the last several decades the ranks of important producing countries have grown. Australia, Finland, and the Philippines have become significant producers of cobalt; Australia, Peru, the Philippines, Poland, and South Africa of copper; Australia and Gabon of manganese, and Australia, Cuba, Indonesia, the Philippines, and South Africa of nickel.

The entry of new countries coupled with the decline of the major traditional producers has reduced the level of country concentration. This, along with a parallel decline in concentration at the firm or enterprise level, has strengthened competition, and made it even more difficult in the cobalt and nickel industries for the dominant producers to control the market price and to earn excess profits over a prolonged period of time. These trends complicate the formation and maintenance of producer cartels, and hence reduce the likelihood of such collusive efforts among producers. They also enhance the security of supply of the major consuming countries, for now an interruption in output from any particular producing country can more easily be made up by other suppliers.

While the shifts described in the location of mining over the last thirty years are of some intrinsic interest, we have reviewed them here in the hope of gaining some insights into the evolution of mining activity in the future. This raises the question, to what extent are past trends likely to continue?

Although there is no way of knowing for certain the answer to this question, where the shifts in mining reported in Tables 2a-d have occurred in a continuous and persistent manner over time, we have more confidence in projecting them into the future. For instance, the share of world nickel production coming from the developed countries fell from 77% to 62% from 1950 to 1960, then to 52% by 1970, and finally to 44% by 1980, while the share of the developing countries consistently rose over this period. On the other hand, a persistent long-run secular trend is less clear for copper. The developing countries saw their share of this market rise modestly from 42% to 44% between 1950 and 1960, then decline to 38% in 1970, before returning to 44% in 1980. Similarly, the share of manganese market supplied by the developing countries climbed from 33% to nearly 40% during the 1950s, where it remained during the 1960s, before dropping to 26% during the 1970s. Had one projected in 1970 the developing countries' share of the manganese market in 1980 on the basis of past upward trends, the result would have seriously overestimated the actual figure.

Even where the trends have been consistent over the last thirty years, as in nickel, projections based on these trends implicitly assume that the important determinants of comparative advantage will continue to change and hence shape the shifts in the location of mining activity in the future as they have in the past. This is a strong assumption that few who ponder it seriously are comfortable making. The possibility of major structural change is always present. During the 1970s, for example, the sharp rise in energy prices is known to have adversely affected the production of nickel from laterite ores. As the shift in nickel production toward developing countries has widely involved the exploitation of laterite deposits, despite its persistence over the last thirty years this shift may not continue during the 1980s and 1990s.

Industry investment plans provide a possible check on the reasonableness of projecting past trends into the near future. Major new mines take several years to develop, and plans to invest in such projects are typically announced 4 to 7 years before they come into operation. Information on the expansion of existing mines, and on the closure of operating mines, is also available. Carefully compiling such information, one can estimate mine capacity into the future and determine whether the distribution of that capacity is consistent with projections based on past trends. At best, however, this approach can provide a picture of the industry five years into the future. Moreover, the clarity of this picture is dimmed by possible changes in announced plans that may subsequently occur in response to short-term market fluctuations and other considerations.

Consequently, in assessing shifts in mining location ten to forty years in the future, one is ultimately forced to identify the major determinants of comparative advantage in mining (where comparative advantage is defined broadly to include the political and other factors affecting future investment and production decisions) and assess how these determinants are changing over time. Over the last two centuries, international trade economists have developed a number of interesting theories for explaining shifts in comparative advantage. For resource trade, the factor endowment theory is usually considered the most relevant. Indeed, it almost seems self-evident that Zaire is a major producer of cobalt because it is well-endowed with cobalt, or that Canada is a major producer of nickel because it is well-endowed with nickel. Yet exactly how to define and measure a country's endowment of cobalt and nickel is not clear. In addition, it is well-known that political instability, fear of expropriation, availability of infrastructure, and other considerations also influence where mining firms invest and produce minerals.

Despite such caveats, recent research (Tilton, forthcoming) on copper, nickel, and a few other mineral commodities suggests that a significant, though far from perfect, relationship exists between the mine output of major producing countries and their reserves[2] ten years earlier. This suggests that the reserve data shown in Tables 2a-d for 1980 can provide some insights into likely shifts in mining over the coming decade.

For cobalt, these figures raise the possibility that the recent downward trend in the developing countries' share of world output may be reversed in the future. More specifically, they suggest that the relative output of Zaire will continue to decline, but that production in the Philippines, Zambia, and other countries will more than offset the relative decline of Zaire. In contrast, the reserves found in developed countries are significantly less than the latter's share of world production. For several reasons, however, considerable caution must be exercised in assessing the implications of the reserve data for cobalt. First, the consuming countries generally consider cobalt a critical and strategic mineral, and twice during the 1970s supplies from Zaire were interrupted due to civil strife. As a result, the consuming countries may prefer to purchase their supplies in more stable, developed countries, even though they may be less well-endowed in terms of reserves than developing countries. Second, outside of Zaire cobalt is widely produced as a by-product of nickel and copper. Measuring reserves in such situations is much more

[2]Reserves indicate the quantity of a mineral commodity found in known (discovered) deposits that are economic to exploit given existing mineral prices and production costs. They are one of several possible measures of mineral endowment, and tend to change over time in response to exploration and the discovery of new deposits, changes in mineral prices, and shifts in production costs.

difficult, and the resulting estimates less reliable.

The geographic distribution of copper reserves suggests that the production of this commodity may shift somewhat during the 1980s toward the developing countries and away from the socialist countries. About one third of world production and reserves are found in the developed market economy countries, and so little change in their future market share is expected.

While the developing countries mined 26% of world manganese production in 1980, they held only 7% of total reserves. So the declining market share of these countries over the last several decades may well continue in the future. According to Table 2c, manganese reserves are highly concentrated in two areas--the Soviet Union with 45% of the world total, and South Africa with 41%. As these two countries produced only 38% and 21% of world output in 1980, their share of world production could increase in the future. However, the major consuming countries may resist becoming overly dependent on these two countries. To the extent this is the case, developing countries and other producers with more modest reserves will have an opportunity to supply more of the world's output than would otherwise be the case.

In contrast to manganese, the reserve figures for nickel imply that an increasing proportion of world output will come from the developing countries. Possessing 63% of world reserves, they accounted for only 34% of mine production in 1980. The developed market economy countries and the socialist countries on the other hand produced more than expected on the basis of their reserves. Here again, the implied shifts may be inhibited or retarded by other considerations. In particular, as noted above, nickel is extracted from two quite different types of mineral ores--sulfide deposits and laterite deposits. In general, the former are more profitable to mine, as they enjoy more valuable by-product recovery, higher recovery rates, and lower processing costs. This last advantage, which derives in large part from the fact that sulfide ores can be concentrated by mechanical means and so require less energy for treatment, has increased in recent years with the rise in energy prices. As a result, the shift of nickel production toward the developing countries may be impeded, for these countries possess some 86% of the world's nickel reserves in laterite deposits, but only 6% of those in sulfide deposits.

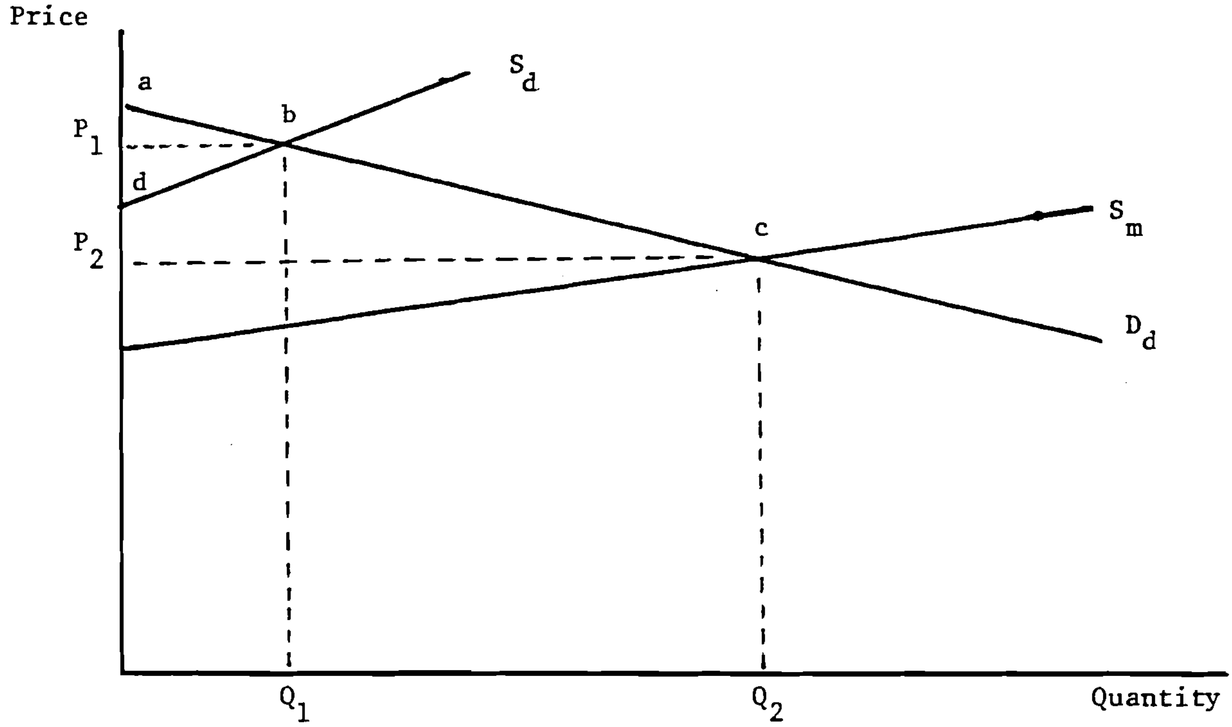
Distribution of Costs and Benefits

According to welfare theory, the changes caused by trade in a country's consumer and producer surpluses reflect the costs and benefits it derives from trade. These changes are illustrated in Figure 1a for an importing country. The curve D_d is the country's domestic demand curve, the curve S_d is its domestic supply curve, and the curve S_m its supply curve for imports. (If the country purchased only a small portion of total world exports, and hence had no impact on the world price, the curve S_m would be horizontal rather than upward-sloping).

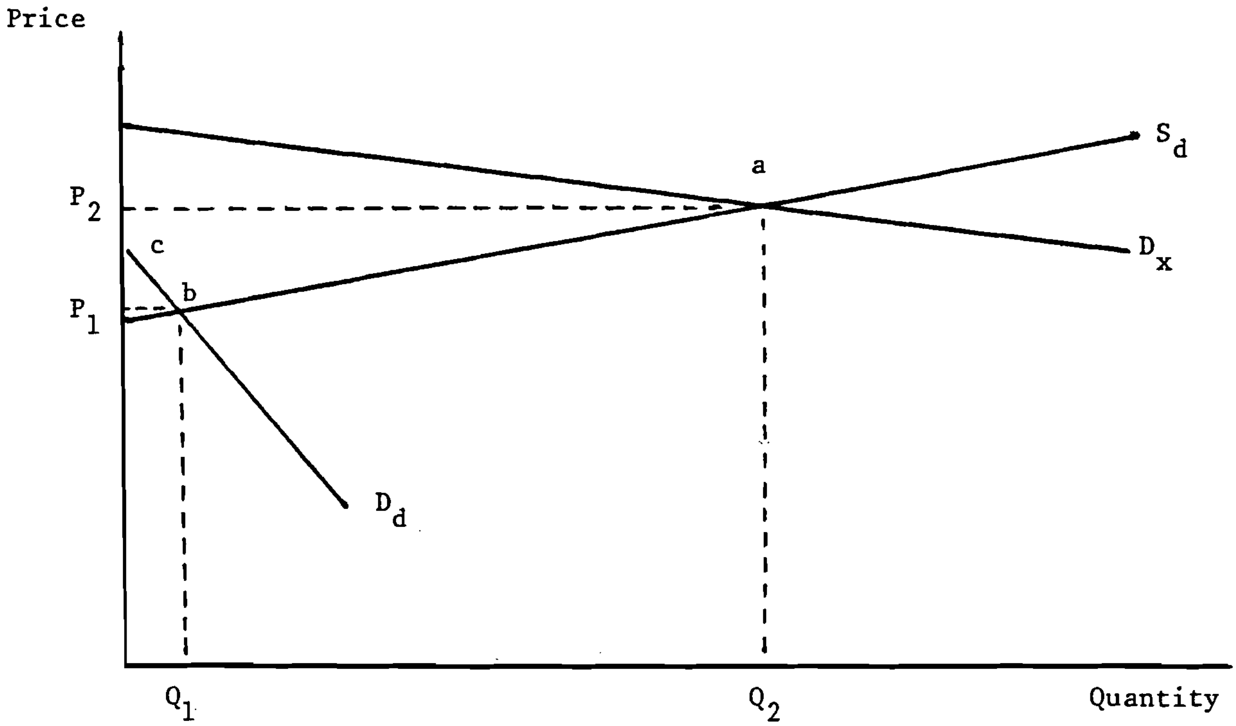
In the absence of trade, the country would produce and consume the quantity Q_1 of the mineral commodity in question at a market clearing price of P_1. Consumer surplus, defined as the difference between what consumers are willing to pay and what they actually have to pay, is given by the area abP_1. Producer surplus, defined as the difference between

Figure 1. Changes in Consumer and Producer Surpluses Due to Trade.

a. Importing Country



b. Exporting Country



the revenues received by producers and their costs, is given by the area P_1bd, assuming that the domestic supply curve S_d reflects the marginal costs of domestic production.

With trade, the country resorts to imports to satisfy domestic demand, as imports are available at lower prices than domestic production. Indeed, according to Figure 1a, domestic suppliers cease production at the new equilibrium price P_2, and domestic demand Q_2 is entirely satisfied by import. (This need not be the case, of course. Some domestic producers may remain competitive even at the lower market clearing price that occurs with trade, and Figure 1a could easily be adjusted to reflect such a situation.) Figure 1. Changes in Consumer and Producer Surpluses Due to Trade.

In any case, trade adversely affects domestic producers by reducing, and in this case eliminating, the producers surplus earned by domestic firms. Consumers on the other hand benefit from trade, as the consumer surplus increases by the area P_1bcP_2. The net benefit--the difference between the gain in consumer surplus and the loss of producer surplus--is thus given by the area $dbcP_2$.

Figure 1b shows the benefits from trade for an exporting country. The curve D_d is the country's domestic demand curve, the curve S_d its domestic supply curve, and the curve D_x its export demand curve. Without trade, domestic supply and demand are equal at the quantity Q_1 and the market clearing price P_1. Trade raises domestic supply to Q_2 and price to P_2. At the latter price, domestic demand is reduced, and in the case illustrated in Figure 1b completely eliminated, causing a decline in consumer surplus. Producer surplus, however, increases substantially, and the net gain to the country from trade is given by the area P_2abc.

The preceding suggests that all one needs to appraise the benefits of trade is a set of supply and demand curves similar to those shown in Figure 1 for the significant importing and exporting countries. One can then derive the benefits for each country, and through simple addition calculate the total benefits from trade for all exporting countries, for all developing countries, or for any other subset of countries. Assessing shifts in benefits among countries over time requires only that the supply and demand be estimated for the future period of interest.

Unfortunately, in practice a number of difficulties, both conceptual and empirical, make it extremely difficult to assess with much accuracy the benefits of trade.

First, it is far easier to draw a hypothetical set of supply and demand curves, as in Figure 1, than actually to determine these curves for specific countries. Econometric studies at best provide a reliable picture of the nature of these curves and their elasticities around the range of prices and outputs that have actually occurred in the past. They cannot estimate the domestic supply curve for an importing country that has had no domestic production, or the demand curve for a producing country that had no domestic consumption. Nor can they provide much information about the nature of the demand curve in importing countries at prices that are five or ten times greater than those ever realized. Yet such information is essential for assessing the consumer surplus of these countries.

Second, supply curves for both importing and exporting countries may not reflect the incremental or marginal costs of production. In particular, large producers with market power have an incentive to limit their output so that price is maintained above their marginal cost. As a result, the area between the supply curve and the market price underestimates the producer surplus they enjoy.

Third, even where the supply curve faithfully reflects the costs firms incur, these private costs may deviate from the social costs borne by the country as a whole. For instance, the cost of labor to firms in developing countries suffering from high unemployment or underemployment may be far above the true social costs measured in terms of the value of the products or services that must be given up because that labor is not available for other purposes. Similarly, an overvalued currency may result in artificially high costs for domestic inputs. Where such discrepancies exist between social and private costs, the domestic supply curve should be adjusted to reflect the former when appraising the producer surplus realized by the country as a whole.

Fourth, the costs and benefits of trade are assessed within a partial, rather than general, equilibrium framework. Consequently, the impact of mineral trade on other sectors of the economy is ignored. Canada and other producing countries have at times expressed concern that their mineral exports keep the value of their domestic currencies relatively high, and in the process inhibit balanced economic development by impeding the growth of their manufacturing and service sectors.

Finally, trade may redistribute income and wealth within a country, accentuating or alleviating disparities. In addition, the government may, through taxes and other means, capture some of the surpluses accruing to producers and consumers. Whether these funds are spent on education, military hardware, economic diversification, or social security greatly affects the ultimate benefits derived from trade. Again, such considerations are ignored when the benefits of trade are assessed simply in terms of the impact on consumer and producer surpluses.

These problems have encouraged some researchers to fall back on trends in prices or producer revenues to appraise how the benefits of mineral trade are shifting over time between consumers and producers. For example, the secular decline in real manganese prices, noted earlier, is often cited as evidence of a shift of benefits from producers to consumers. Yet a little consideration clearly indicates that this is not necessarily a valid conclusion. If the decline in prices is the result of a downward shift over time in the world demand curve, both the consumer and producer surpluses have declined. In the process, the proportion of total benefits going to producers could have decreased or increased. The declining price, however, has more likely been the result of a downward shift in the world supply curve caused by major advances in earth-moving capabilities and other technological developments along with the opening up of large, low-cost deposits over time. So while prices have declined, so have production costs. Whether on balance producers have received a larger or smaller surplus, and whether this surplus constitutes more or less of the total benefits generated by trade, is not known.

What is clear, however, is that such changes tend to redistribute the available producer surplus. Traditional producers whose costs do not decline as much as the price falls find their benefits diminishing, while others enjoy greater returns from trade. The adjustments forced on the former can be quite painful, particularly if these countries derive a substantial share of their government revenues and foreign exchange earnings from mineral trade. They understandably are likely to complain that prices are not "remunerative and just" for producers, even when the surplus realized by all producers has actually increased.

Producer revenues, which can easily be derived by multiplying the average price a country receives for a mineral product times its output or shipments, are also on occasions used as a measure of the benefits from trade. In addition to the ready availability of the necessary information, this procedure is justified on the grounds that private costs often exceed the social costs of mineral production in developing countries. Furthermore, developing countries generally attach great importance to the acquisition of foreign exchange, and where output is largely or entirely exported, producer revenues approximate the foreign exchange a country earns from its output.

Nevertheless, producer revenues suffer from several serious defects as a measure of the benefits that even developing countries derive from mineral trade. In particular, certain inputs used in mining and processing minerals, such as capital, technology under license, and expatriate labor, are likely to come from abroad and so require foreign exchange to acquire. As Mikesell (1975) and others have pointed out, such costs should be subtracted from producer revenues to obtain the net foreign exchange earnings or retained value of mineral production. Even after making this adjustment, the remainder reflects the benefits of trade to the host country only if all the domestic resources used in mining and processing have no social value in the sense that they could not be used elsewhere in the economy. While such an assumption may at times appear plausible for unskilled labor, for other domestic inputs, such as skilled labor, management, materials, and producer goods, it seems most implausible.

Unfortunately, there are no easy shortcuts or convenient rules of thumb for measuring the benefits of trade. Trends in prices, producer revenues, and even retained value, though used on occasion for this purpose, can be misleading. To appraise the benefits of mineral trade, one is forced to assess consumer and producer surpluses. This, in turn, requires information on the price that consumers pay and that producers receive, on the production cost of producers, and on the prices that consumers would be willing to pay if necessary.

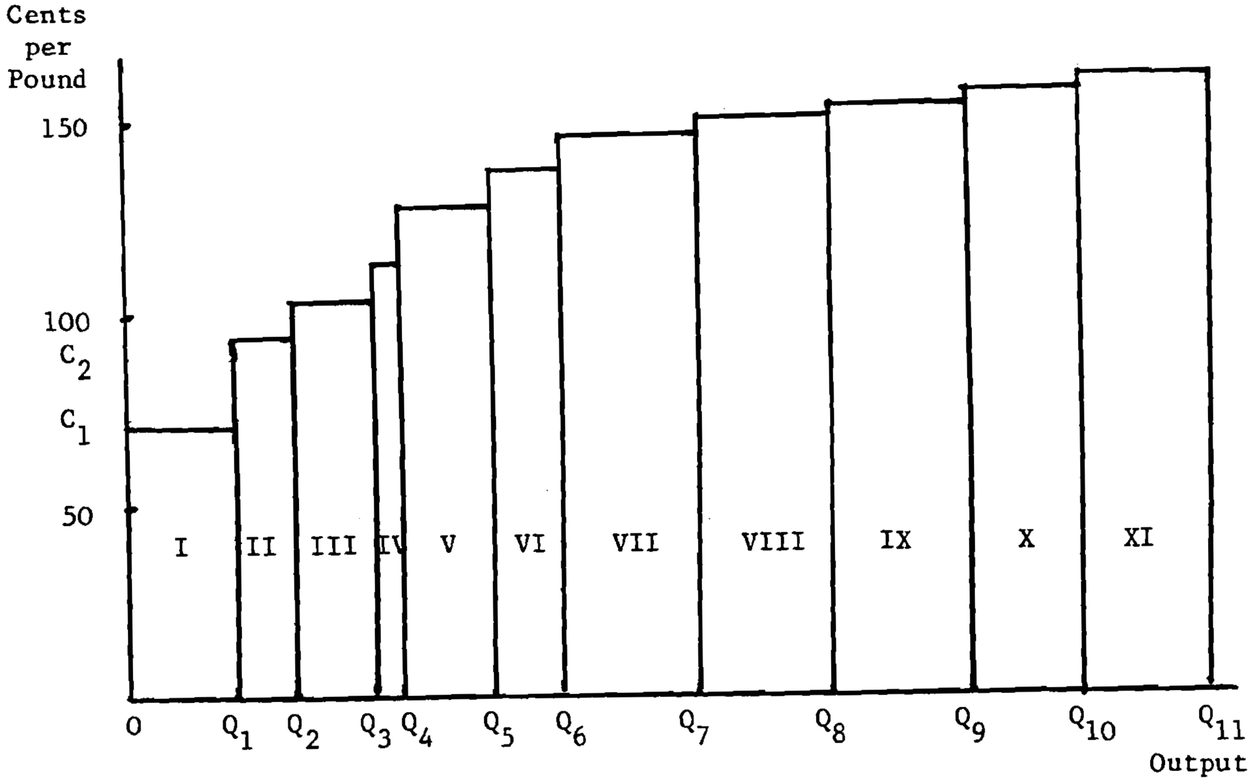
Reliable estimates of what consumers are prepared if necessary to pay are particularly difficult to obtain. In part, this is because the number of end uses is quite high for most minerals, making it impractical to assess the marginal benefit of the commodity to each. Moreover, since the introduction of seabed mining and its resulting impacts are likely to occur gradually over a number of years, the information needed is not how much a particular user would pay over the next month or even year if necessary, but rather how much he would demand at various prices after he had ample time to install the necessary equipment and to develop new technologies for substituting alternative materials or for conserving the material in question. In other words, the information needed pertains to the shape and nature of the long-run rather than short-run demand curve. As this curve is affected by price-induced technological change and as the timing and impact of technological change are inherently difficult to anticipate, it is not easy to obtain reliable estimates of the long-run supply curve, and hence of consumer surplus. While this is particularly true for supply curves 10 or 40 years in the future, it is also the case for curves that pertain to the present.

If one is primarily interested in the benefits of mineral trade for producers, insights into the evolution of these benefits over time can be obtained from information on prices and production costs. Here the prospects of obtaining the necessary information appear somewhat more promising. On the basis of grade of ore, size of deposit, and other considerations, mineral producing firms, consulting organizations, and government agencies have estimated the production costs associated with both operating and potential mines.[3] This information can be used to approximate a long-run marginal cost curve for the industry, which if the latter is competitive corresponds to the long-run supply curve.

Such a curve is illustrated in Figure 2 for copper. Production costs per pound are shown on the vertical axis and annual output at designated capacities on the horizontal axis. The lowest cost mine, indicated by I, has average production costs (including a normal rate of profit) of OC_1 and an annual output of OQ_1. The second lowest cost mine, identified as

[3]In most cases, this information is proprietary and not readily available. However, the U.S. Bureau of Mines has been accumulating such cost information for its Minerals Availability System, and has actually constructed cost curves for operating copper mines in the United States similar to the curve shown in Figure 2 (Davidoff 1980).

Figure 2. Average Production Costs for Existing and Potential Copper Mines.



II, has average costs of OC_2 and output of Q_1Q_2. This figure shows the costs and output for a number of other mines, and in actually constructing such a figure one would want to include all existing and potential mines. The production cost for mines that recover by-products and co-products should be net of the credits these products produce. Where the product itself is a by-product, as is the case for most cobalt production outside Zaire, only those costs should be counted that occur after separation from the main product has taken place.[4]

Figure 2 shows production costs rising rather sharply initially and then leveling off at about 1.50 dollars per pound of copper. On the basis of available evidence, this is probably a reasonable assumption, as a number of large porphyry copper deposits become economical at about that price. This tendency for the long-run supply curve to become horizontal at larger output levels may be true for cobalt, manganese, and nickel as well. If so, and if demand is sufficient to require production from at least some of the relatively high-cost deposits, then cost curves similar to those illustrated in Figure 2 provide information on both production costs at different mines (and hence in different producing countries) and the approximate long-term market clearing price. This, it will be recalled, is all that is needed to assess producer surplus for individual countries or for groups of countries.

Estimating the overall magnitude and geographic distribution of producer surplus in the future, even on the assumption of no seabed mining, is somewhat more difficult. Over time, production costs are likely to rise

[4]For an interesting conceptual discussion regarding the long-run supply curve for mineral commodities produced as by-products, see Brooks (1965).

or fall with changes in technology, real labor costs, capital equipment costs, and other factors. These changes, however, may not create the obstacles that one might first imagine. This is because producer surplus is not affected by parallel shifts, either upward or downward in the long-run cost curve, but only by changes in its internal shape. In this connection, what is particularly important is the size and number of mines operating with cost below the market price, and the extent to which their costs rise or fall over time relative to that price. Such changes may occur for two reasons. First, the cost differential between marginal and intramarginal mines may widen or narrow. For instance, the differential may be reduced by the shutting down over time of a number of low-cost mines as their ore bodies are depleted. Alternatively, the cost advantage of low-cost mines may be enhanced by an increase in energy prices, as appears to be the case for sulfide deposits in the nickel industry. Second, if one or several dominant producers exercise market power and as a result a differential exists between the market price and the cost of marginal producers, any change over time in this differential will affect the surplus realized by producers. A shift towards a more competitive market structure, for example, would diminish it.

While it is not possible to anticipate such changes with great precision, a careful examination of trends in market structure, prices of factor inputs, production technology, and other relevant factors can provide some insights into how producer surplus is likely to evolve, both in terms of its overall magnitude and its distribution among countries.

IMPACTS OF SEABED MINING

This section examines the possible impacts of seabed mining over the next forty years. The focus again is on the production costs and prices of the mineral commodities contained in seabed nodules, the location of mining, and the benefits from mineral production and trade.

Prices and Production Costs

Seabed mining is unlikely to raise the production costs or prices of cobalt, copper, manganese, and nickel above what they otherwise would be, for if it were actually more expensive than the output from marginal land-based producers, there would be no economic incentive to engage in seabed production. Aside from this constraint, however, the range of possible impacts on costs and prices is quite wide.

At one extreme, seabed mining could have little or no impact. This would be the case, for example, if seabed mining proved uneconomical or for other reasons was not undertaken on a commercial scale. In addition, given the mineral composition of seabed nodules, limited commercial production is unlikely to have much impact on copper production costs and prices, simply because the quantities produced would constitute such a small proportion of total world output. Seabed mining may also have a negligible impact on manganese costs and prices, even with substantial commercial seabed mining, if the most attractive production technology excludes the recovery of manganese.

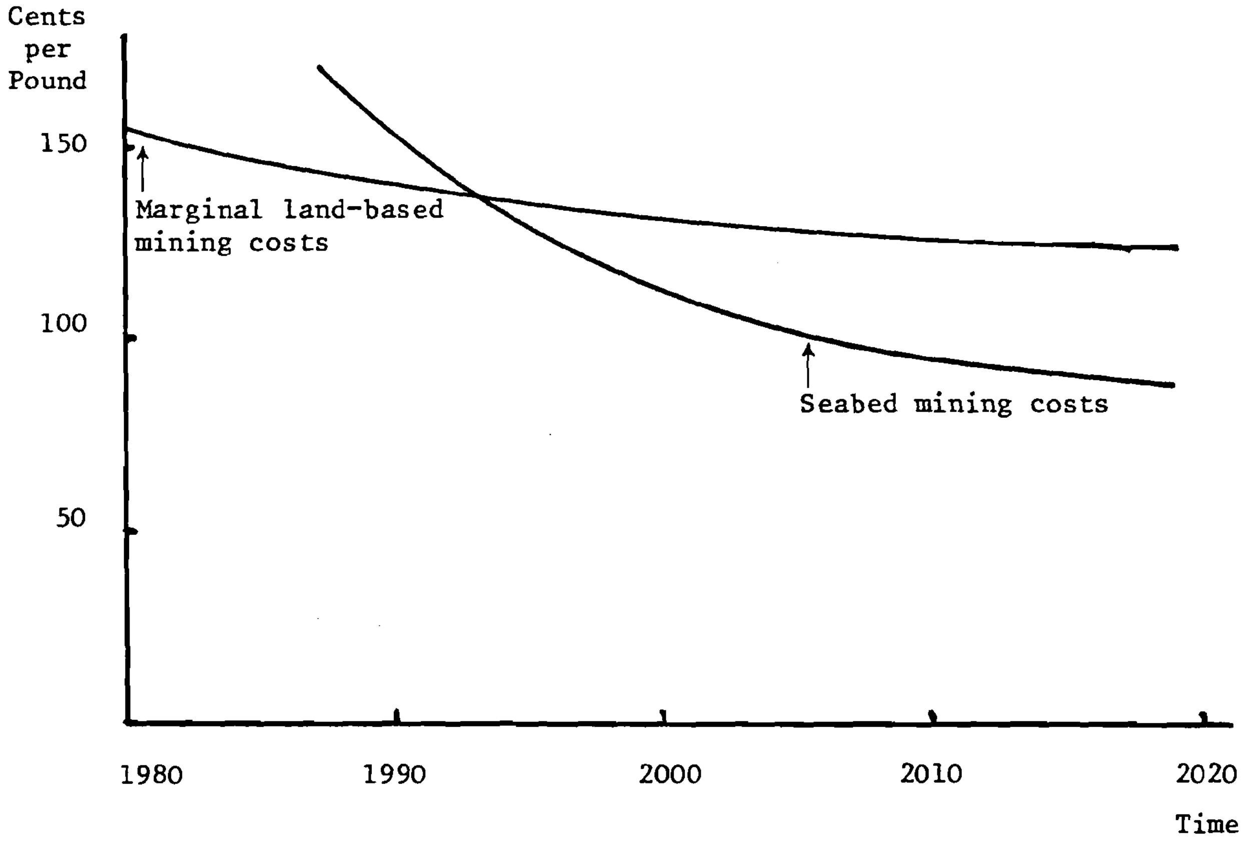
A second possibility is that real production costs and prices will rise but at a slower rate than otherwise as a consequence of seabed mining. The depletion of low-cost mines forces society over time to rely on poorer quality deposits. This, in turn, tends to shift the long-run supply curve for minerals outward. As this shift occurs, seabed mining may offer an attractive alternative to the development of high-cost land-based deposits, and in the process help relieve, though not eliminate, the upward pressure on costs and prices.

Finally, seabed mining could conceivably result in lower real mineral prices. This possibility has on occasion been denied, on the grounds that if seabed mining could produce mineral commodities at costs below those of land-based producers, it would already be a reality.[5] This static argument, however, fails to take account of the dynamic effects of technological change over time. Scientific developments have greatly enhanced the prospects for the economic recovery of minerals from seabed nodules over the last twenty years, and such developments are likely to continue in the future. Moreover, once the commercial production of seabed nodules is actually underway, costs are likely to fall as experience and learning accumulate. Consequently, the production costs of seabed mining may decline over time relative to both the current and future costs of land-based operations. Such a possibility is illustrated in Figure 3, which shows seabed mining costs falling below those of marginal land-based producers over time, even though the latter are declining as a result of the cost reducing effects of new technology and other factors.

Furthermore, even if one excludes the possibility that such dynamic considerations may make seabed mining more profitable and attractive relative to land-based production over time, the real price of cobalt, and

[5]See, for example, Ontario, Ontario Mineral Resources Branch (1980).

Figure 3. Possible Changes Over Time in Average Production Costs for Copper.



possibly, manganese, could decline as a result of seabed mining. This is because the cobalt and manganese contained in nodules could satisfy a significant share of total world demand even at rather modest rates of seabed production. As price starts to drop, the critical question would then be whether land-based or seabed producers would cease mining cobalt and manganese and thereby keep prices from dropping greatly. Although the economic and technological factors determining the answer to this question are not totally clear, most of the consortia preparing to engage in seabed production are not planning to produce manganese. Apparently they do not expect the future market price to cover the incremental costs of recovering manganese following the separation of copper, cobalt, and nickel from the ore. In contrast, current plans call for the production of cobalt, as the incremental processing costs are presumed to be below expected future prices. So cobalt prices could decline in real terms, even if seabed mining as a whole is economical only under rising real prices on average for the minerals it produces.

So far the discussion has assumed that prices follow or parallel shifts in the costs of marginal producers caused by seabed mining. This is a reasonable assumption over the long run for competitive industries, such as copper and manganese. With nickel and cobalt, where one or a few producers have in the past tended to dominate production and set a producer price, seabed mining by providing a new source of supply should promote more competition and reduce the market power of the major traditional producers. This, in turn, would encourage the long-run price to move toward, and eventually approximate, the long-run costs of marginal producers, whether they are high-cost land-based producers or seabed miners. In this case, real mineral prices could fall in response to seabed mining, even though production costs might be increasing. As pointed out earlier, however, the nickel and cobalt markets have in recent years experienced a considerable increase in competitive conditions, and as a consequence a significant discrepancy between long-run prices and marginal production costs may no longer exist.

Location of Mining

In examining the impacts of seabed mineral production on the location of mining, it is convenient to begin by assuming the cheapest deposits will be developed first, regardless of their location, and then to relax this assumption. It is also useful to differentiate, as in the previous section, between three possible situations: in the first, seabed mining has no impact on mineral prices; in the second, prices rise but less than in the absence of seabed mining; and in the third, prices actually fall due to seabed production.

The first situation should have little or no influence on the location of mining activity. Seabed production either does not occur, or takes place on such a modest scale that the mineral market of interest is unaffected.

With the second situation, where real prices rise but more slowly than in the absence of seabed mining, existing land-based mines continue to be profitable and remain in operation until their reserves are depleted. Their productive lives, however, may be shortened, for additions to their reserves will occur more gradually over time due to the slower rise in price. In addition, the development of new land-based deposits will occur at a more modest pace, as the decline in the rate of increase in price will dampen the incentives to conduct exploration and hence retard the discovery of new land-based deposits. It will also slow the shift of known deposits from submarginal to marginal status. As a result, mining will shift away from the land and toward the sea.

The third possible situation, where real prices actually fall, could force the closure of operating land-based mines even though the latter still contain substantial quantities of minerals that would be profitable to exploit at previous prices. The likelihood of such closures, however, is reduced by the high capital costs required to develop most land-based mines. Since these costs are sunk and cannot be recovered when the mine shuts down, the decision to stop production becomes economical only if price drops below the out-of-pocket or variable costs of production. Still, the tendency toward earlier exhaustion, identified in the previous situation, is accentuated. Moreover, unless exploration uncovers new deposits with costs below those of the existing marginal land-based producers, all new mine development will take place at sea.

The impact of the shift from land to sea production that occurs under the last two situations on the output of particular producing countries or groups of countries depends on their relative production costs. Countries with undeveloped deposits that are just marginal will suffer the most, in that the development of these deposits either will occur more slowly or not at all. The large undeveloped porphyry copper deposits in Chile and Peru, for example, fall into this category. If seabed mining causes prices actually to fall, it will again be the marginal land producers that are most adversely affected, but in this situation both operating as well as potential mines could suffer. In nickel, for example, the high-cost laterite deposits found mostly in the developing countries are likely to bear the brunt of any curtailment in land production, while output from the relatively low-cost sulfide deposits found in Canada and other developed countries would be little affected.

If one now relaxes the assumption that known deposits are exploited over time in order of their relative production costs, it is clear that other considerations may also affect the future location of mining. The governments of the major industrialized countries, for instance, may be prepared to subsidize seabed production, should it prove somewhat more expensive than land-based mining, to diversify their sources of supply and reduce their vulnerability to import interruptions. Conversely, if seabed mining proves a serious threat to land-based producers, host governments may protect and subsidize the latter, rather than accept the social dislocation and other costs associated with domestic mine closure. If followed by a number of countries, such behavior could precipitate a substantial decline in mineral prices, and leave large segments of the land-based mining industry unprofitable. While the extent to which political decisions are likely to override the underlying economic determinants of mining location is difficult to predict, clearly such decisions could have a major influence on the geographic distribution of mining activity in the future.

Distribution of Costs and Benefits

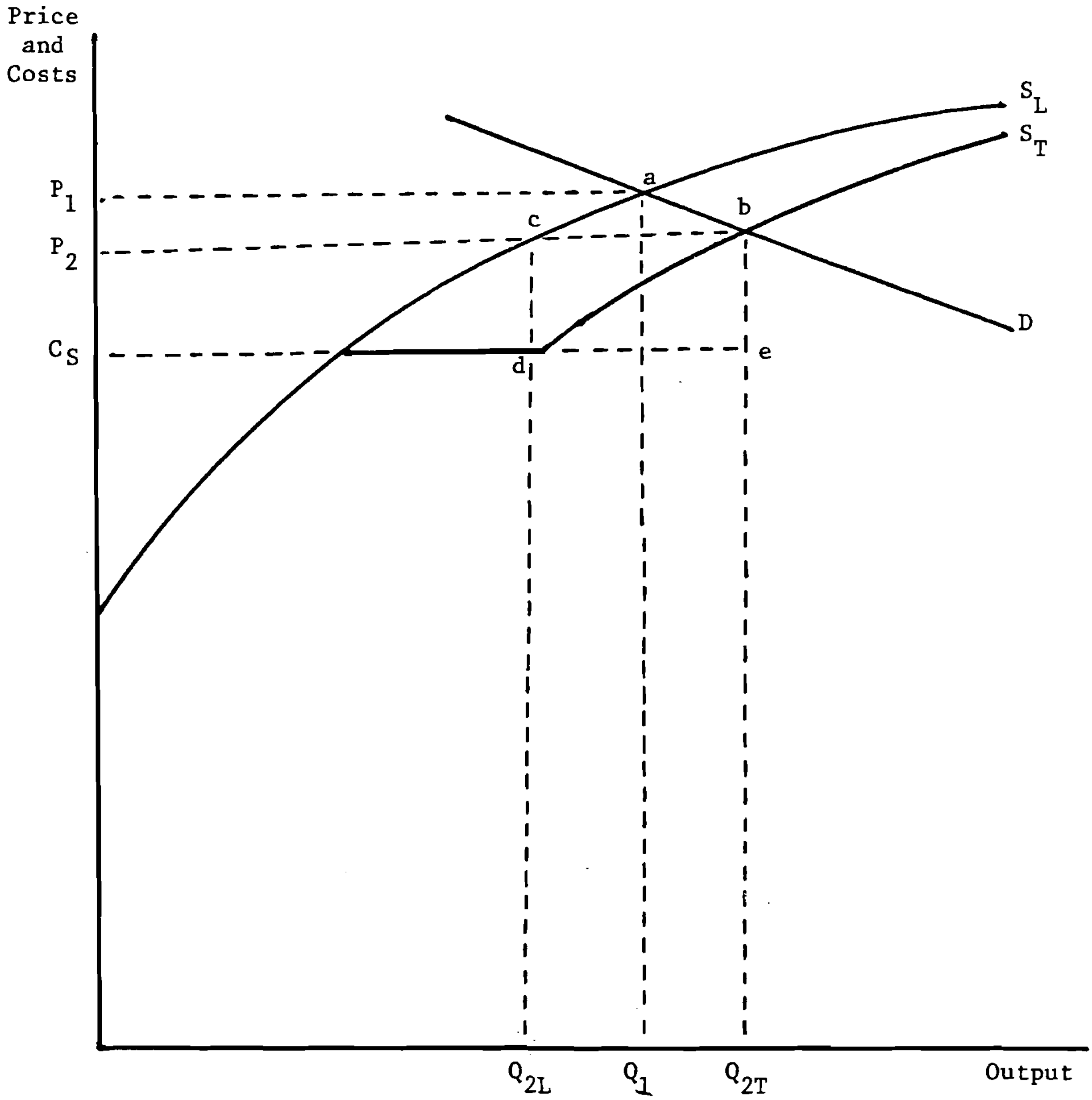
The global costs and benefits associated with the seabed mining of nickel are depicted conceptually in Figure 4. Similar figures could be constructed for cobalt, copper, and manganese.

The curve D in Figure 4 reflects the long-run world demand curve for nickel at the time under consideration. The curve S_L is the long-run supply curve for land-based producers. Assuming the industry is relatively competitive, the latter is approximated by a smoothed version of a step cost curve similar to that shown in Figure 2 for copper. In the absence of seabed mining, the quantity Q_1 is produced and consumed at the market clearing price P_1.

Now, if production from seabed sources is limited to a fixed quantity, and if seabed production costs over this permissible range are constant at C_S and lower than those of marginal land-based producers, the total supply curve for nickel from both land- and sea-based deposits can be drawn as S_T in Figure 4. This curve coincides with the supply curve for land-based producers at low prices, and then shifts to the right at a price equal to C_S by the amount of allowable seabed production. At higher prices, the total supply curve lies to the right of the supply curve of land-based producers by an amount equal to the ceiling on seabed production.[6]

[6]Both the assumption of fixed costs over the relevant range of seabed production and the assumption of a fixed ceiling on seabed production could be relaxed. This would require a modification of Figure 4, which would complicate the exposition, but not change the basic conclusions regarding the distribution of the costs and benefits of seabed mining.

Figure 4. Changes in Consumer and Producer Benefits Due to Seabed Mining.



With the addition to total supply from seabed mining, Figure 4 shows the equilibrium price drops to P_2. At this lower price, world demand increases to Q_{2T}. Seabed production is just sufficient to provide for this increase in demand and to make up for the reduction in land-based production from Q_1 to Q_{2L}.

The fall in market price coupled with the decline in land-based output causes the producer surplus to diminish by the amount represented in Figure 4 by the area P_1acP_2. World consumers, on the other hand, enjoy an increase in their surplus equal to the area P_1abP_2, which exceeds the loss of land-based producers by the amount abc. In addition, a surplus equal to the rectangle cbed is realized by seabed producers, so the net global benefit is abedc. Some of the producer surplus earned by seabed miners can, of course, be taxed and redistributed to other parties.

It is interesting to note that the welfare costs of seabed mining are borne by the land-based producers, and that this loss is greatest per unit of output for the relatively low-cost producers that remain in business after seabed mining is underway. The higher cost land-based producers that are either kept out or pushed out of the industry by seabed production have smaller surpluses or rents, which they would otherwise have realized, and so lose less.

The increase in consumer surplus caused by seabed mining is enjoyed by all consuming countries. Since even the land-based producing countries are consumers, some of their producer loss is offset by consumer gains. Yet, as is well known, the largest consumers are the major industrialized countries--the United States, Japan, and member states of the EEC and CMEA--and it is these countries that potentially have the most to gain. However, as Figure 4 suggests, the amount by which the consumer surplus increases and hence the benefits flowing to the industrialized countries can be curtailed by limiting the amount of mineral production permitted from the seabed. The smaller this limit, the less price will decline and consumer surplus will increase.

The second surplus produced by seabed mining goes initially to those firms and consortia engaged in this activity. Although these producers are likely to come primarily from the major industrialized countries, as noted earlier, much of this surplus can be captured through royalties and other means, and redistributed to developing countries, adversely affected land-based producers, or other groups.

This discussion of the costs and benefits associated with seabed mining rests on certain assumptions that should be noted explicitly. In particular, the supply curve for land-based producers S_L is presumed to reflect the social as well as private costs of production. If this is not the case, and if one is interested ultimately in the costs and benefits of seabed mining for society in general, rather than private producers, this curve should be modified to take account of such discrepancies before the shifts in producer and consumer surpluses are measured. In addition, and of much greater importance, the analysis has implicitly assumed that seabed mining is or will soon be competitive with land-based production. This is far from certain. If seabed mining does not take place within the foreseeable future, none of the shifts in costs or benefits attributed to this activity will occur.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The possible impact of seabed mining has been examined in three specific areas--prices and production costs, location of mining activity, and the magnitude and geographic distribution of the benefits from mineral production and trade. The analysis has been largely conceptual in nature, with little or no attempt actually to quantify anticipated impacts. Despite this fairly narrow scope, two general conclusions emerge:

1. Measuring the future impacts of seabed mining is an extremely complicated and difficult endeavor. To begin with, forecasting mineral markets ten to forty years into the future, even in the absence of seabed mining, is fraught with difficulties. Of course, certain trends can be discerned and projected into the future. Mineral markets in general are becoming more competitive over time as the number of major producing firms and countries increase. Production is shifting from the developed to the developing countries for some mineral commodities, and from the developing to the developed countries for others. Long-run secular trends in real prices can also be identified. They are down for some minerals, constant for others, and up for still others. While some of these past trends are likely to continue into the future, others will be reversed by higher energy prices, new technologies, or other developments. Forecasting which trends will continue and which will not is a hazardous business, where at best only partial success can be expected.

Even if such trends in mineral markets could be reasonably predicted, the actual amount of seabed mining that will take place over the next forty years is unknown. The relative costs of seabed and land-based production are the subject of much discussion and disagreement. How scientific breakthroughs and other technological developments will alter future costs is simply unknown, and to some extent unknowable. Moreover, relative costs alone will not be the only determinant of the future level of seabed mining. Industrialized countries may support such production to lessen their dependence on foreign producers. Distressed land-based producers may receive assistance from their own governments, and protection in the form of constraints on seabed production negotiated through international agreements. In the end, seabed production may be influenced as much by such political decisions as economic considerations. Anticipating the future course of the important political decisions is not easy.

Finally, even if the future level of seabed mining could be ascertained, its impacts would still be difficult to assess ex ante. Such assessments may require knowledge about segments of the long-run supply and demand curves far from the observed price and output equilibria of the past. This limits the use of econometric and other quantitative techniques. Nor is it clear how these curves will shift over the next several decades in response to resource depletion, technological progress, the introduction of new materials, changes in the mineral policies (perhaps in response to the perceived threat of seabed production), and other factors.

2. The potential impacts of seabed mining appear to vary over a wider range and to be less bounded than often presumed. For example, the first commercial mining of seabed nodules is widely anticipated to take place sometime during the 1990s, and several consortia are

expected to be in operation by the end of the century. Yet the necessary technology, particularly on the scale required, has not yet been proven. Nor is it completely clear that the requisite public policies to protect the needed private investment are in place. These uncertainties raise the possibility that seabed mining could suffer a fate similar to that of oil shale, where for years commercial production has appeared imminent and yet this goal seems as elusive today as twenty years ago.

On the other hand, the maximum impact that seabed mining could have is at times not fully appreciated. This is clearly illustrated by the argument that seabed mining could not force existing land-based mines to close. As pointed out earlier, the rationale for this position overlooks the potential influence of new technology and learning by doing, on the relative costs of seabed and land-based mining. It also ignores the coproduct nature of seabed production, and the substantial effect of even limited production on the cobalt and perhaps manganese markets.

In short, the development of new and unconventional technologies involves dealing with the unknown and entails great uncertainty. This is particularly true for seabed mining, as the extent of its success ultimately will depend not only on economic and technological considerations but also on political developments. As all of these factors are difficult to predict and potentially erratic in their behavior, the impacts of seabed mining over the next forty years on the welfare of land-based producers, consumers, and other groups range over an extremely broad spectrum, from negligible to overwhelming.

These general conclusions--that seabed mining could conceivably have rather dramatic impacts, but that determining whether this will actually be the case is extremely difficult--are not terribly comforting for those whose future welfare could be substantially altered by seabed mining. This raises the question, how might future research on this issue cope with the inherent complexities and narrow the range of possible outcomes, so that appropriate policies might be undertaken to promote the beneficial effects of seabed mining while alleviating the adverse consequences? In considering this question, two distinct lines of research, which could be carried out separately, appear worth pursuing.

The first and probably most difficult would focus on the expected evolution of mineral production from seabed nodules over the next forty years. At the earliest, when might seabed mining begin? What are the best point estimates of seabed production for 1995, 2000, 2010, and 2020? Can a confidence interval be calculated for each of these estimates? This effort would entail a continuation and extension of the work by Nyhart et al. (1978), Diederich et al. (1979), and Charles River Associates (1981) on the costs of seabed mining. The expected impact of technological progress and learning by doing on future costs would have to be assessed, and the findings compared with those of marginal land-based producers. The conclusions regarding the potential profitability of seabed mining would then have to be adjusted for possible subsidies or constraints resulting from political decisions.

While the probability of identifying all of the important factors that will ultimately determine the future level of seabed mining and their future impact on this activity is not high, the level of seabed production will clearly be one of the major, if not the major determinant of the eventual impact of this activity on land-based producers and consumers.

The second line of research would assess the expected impacts of seabed mining on the assumption that production from this source grows over time in a given manner. In light of the inherent difficulties of actually forecasting seabed output, various growth patterns could be specified and their impacts assessed. Here too there is some literature, in large part the work of Adams,[7] that such an inquiry could build on and extend.

What essentially is required is a better understanding of the long-run demand curves for cobalt, copper, manganese, and nickel, and of the long-run supply curves from land-based production for these commodities. Not only is a better picture needed of these curves as they exist today, but also of how they are likely to evolve in the future. Econometric models and other quantitative techniques can provide some of the information needed. In particular, if properly specified, they can document the nature of the current supply and demand functions over the range of recent outputs and prices. Other techniques can then supplement this information to trace out other parts of the current curves, and to appraise their likely shifts over time.

In the case of cobalt, for example, more information is needed on its various actual and potential end uses and on its production costs. Should the price of cobalt approach that of nickel, in what uses and to what extent would it be substituted for nickel? How large are these potential

[7]In the early 1970s, Adams conducted a number of econometric studies on the impacts of seabed mining for the United Nations Conference on Trade and Development. For a list of these and other studies, see references cited in Adams (1980).

cobalt markets now? How large are they likely to be in the future? How will the development of new composites, plastics, ceramics, and other materials, along with improved processing techniques enhancing the properties of steel and other traditional materials, affect the future demand for cobalt? To what extent has the recent instability in the cobalt market caused by interruptions in supply from Zaire encouraged research and development activity that will ultimately reduce the long-run demand for cobalt? To what extent has this instability also shifted investment and in turn the future location of mining away from central Africa? How do production costs vary among the land-based producers, both for those mining cobalt as a main product and for those mining cobalt as a byproduct? How are these costs likely to shift over time? To what extent will Zaire, perhaps with the help of Zambia, possess the market power needed to control the price of cobalt over the long run?

While no amount of research can answer such questions for certain, either for cobalt or for the other mineral commodities found in seabed nodules, a considerable amount of qualitative information is available from metallurgists, market analysts, mining engineers, and other specialists that can be used to piece together a picture of the long-run mineral supply and demand curves. The challenge lies in identifying and collecting the pertinent qualitative information, integrating it with feasible quantitative analyses, and then analyzing and interpreting the results in an appropriate manner. Here judgement and skill, along with diligence, are essential.

Moreover, given the qualitative components of such analysis, it must be recognized that no universally accepted statistical measures or rigorous rules exist for assessing the reliability or accuracy of the findings. Judgements regarding assumptions and interpretation must be made, and will inevitably be called into question.

Such problems, however, bedevil all important and still unresolved issues. Otherwise, the research required would long since have been carried out.

REFERENCES AND SELECTED BIBLIOGRAPHY

Adams, F.G. 1980. The Law of the Sea Treaty and the Regulation of Nodule Exploration. *Journal of Policy Modeling 2* (1): 19-33.

Antrim, L., P.L. Spencer, and W.W. Woodhead. Circa 1979. *Cobalt, Copper, Nickel and Manganese: Future Supply and Demand and Implications for Deep Seabed Mining.* U.S. Office of Ocean, Resource and Scientific Policy Coordination, Washington, D.C.

Barnett, H.J. 1979. Scarcity and Growth Revisited. Pages 163-217 in: *Scarcity and Growth Reconsidered.* Ed. V.K. Smith. Baltimore, Johns Hopkins.

Barnett, H.J., and C. Morse. 1963. *Scarcity and Growth.* Baltimore: Johns Hopkins.

Brooks, D.B. 1965. *Supply and Competition in Minor Metals.* Baltimore: Johns Hopkins.

Bulkley, I.G. 1979. *Who Gains from Deep Ocean Mining?* Research Series No. 40. Berkeley: Institute of International Studies, University of California.

Cameron, H., G. Ford, A. Garner, M. Gibbons, and T. Marjoram. 1980. *Manganese Nodule Mining: Issues and Perspectives.* Marine Resources Project. Manchester: The University.

Charles River Associates. 1968. *Economic Analysis of the Nickel Industry.* Report prepared for the U.S. General Services Administration. Cambridge, Massachusetts.

Charles River Associates. 1969. *Economic Analysis of the Cobalt Industry.* Report prepared for the U.S. General Services Administration. Cambridge, Massachusetts.

Charles River Associates. 1970. *Economic Analysis of the Copper Industry.* Report prepared for the U.S. General Services Administration. Cambridge, Massachusetts.

Charles River Associates. 1981. *Analysis of Major Policy Issues Raised by the Commercial Development of Ocean Manganese Nodules.* Report prepared for the U.S. National Science Foundation and the U.S. Bureau of Mines, Boston.

Davidoff, R.L. 1980.*Supply Analysis Model (SAM): A Minerals Availability System Methodology.* U.S. Bureau of Mines Information Circular 8820. Washington, D.C.: U.S. Bureau of Mines.

Diederich, F., W. Mueller, and W. Schneider. 1979. *Analysis of the MIT Study on Deep Ocean Mining- - Critical Remarks on Technologies and Cost Estimates.* Research Institute for International Techno-Economic Co-operation, Technical University, Aachen.

Fischman, L.L. 1980. *World Mineral Trends and U.S. Supply Problems.* Research Paper R-20. Washington, D.C.: Resources for the Future.

Herfindahl, O.C. 1959. *Copper Costs and Prices: 1870- 1957.* Baltimore: Johns Hopkins.

Levy, J.P. 1979. The Evolution of a Resource Policy for the Exploitation of Deep Sea-Bed Minerals. *Ocean Management* 5: 49-78.

McKelvey, V.E. 1980. Seabed Minerals and the Law of the Sea. *Science* 209: 464-472.

Metallgescellschaft. Annual. *Metal Statistics*. Frankfurt am Main. Federal Republic of Germany.

Mikesell, R.F. 1975. *Foreign Investment in Copper Mining*. Baltimore: Johns Hopkins.

Newman, J.E. 1982. *Measuring the Economic Effects of Deep Sea Mining on Less Developed Countries*. Unpublished MS Thesis. Cambridge, Massachusetts: Department of Materials Science and Engineering, Massachusetts Institute of Technology.

Nyhart, J.D., L. Antrim, A. Capstaff, A.D. Kohler, and D. Leshaw. 1978. *A Cost Model of Deep Ocean Mining and Associated Regulatory Issues*. Report MITSG 78-4. Prepared for the U.S. National Oceanic and Atmospheric Administration. Cambridge, Massachusetts: Sea Grant Program, Massachusetts Institute of Technology.

Ontario, Ontario Mineral Resources Branch. 1980. *The Future of Nickel and the Law of the Sea*. Mineral Policy Background Paper No. 10. Toronto.

Tilton, J.E. Forthcoming. *Metal Trade Patterns*. University Park, Pennsylvania: Department of Mineral Economics, Pennsylvania State University.

U.N. Conference on Trade and Development. 1977. *Consideration of International Measures on Manganese: The World Market for Manganese:*

Characteristics and Trends. Report TD/B/IPC/-Manganese/2. Prepared by the UNCTAD Secretariat. Geneva.

U.N. Department of Technical Co-operation for Development. 1980. *The Nickel Industry and the Developing Countries.* Report ST/ESA/100. Prepared by consultant S. Zorn. New York.

U.N. Ocean Economics and Technology Office. 1979. *Manganese Nodules: Dimensions and Perspectives.* Dordrecht, Holland: Reidel Publishing.

U.S. Bureau of Mines. 1977. *Cobalt- - 1977.* Mineral Commodity Profiles. MCP-5. Prepared by S.F. Sibley. Washington, D.C.

U.S. Bureau of Mines. 1977. *Copper- - 1977.* Mineral Commodity Profiles. MCP-3. Prepared by H.J. Schroeder. Washington, D.C.

U.S. Bureau of Mines. 1977. *Manganese- - 1977.* Mineral Commodity Profiles. MCP-7. Prepared by G.L. DeHuff and T.S. Jones. Washington, D.C.

U.S. Bureau of Mines. 1977. *Nickel- - 1977.* Mineral Commodity Profiles. MCP-4. Prepared by J.D. Corrick. Washington, D.C.

U.S. Bureau of Mines. 1980. *Cobalt.* A Chapter Preprint prepared by S.F. Sibley for the 1980 *Mineral Facts and Problems.* Washington, D.C.

U.S. Bureau of Mines. 1980. *Copper.* A Chapter Preprint prepared by H.J. Schroeder and J.H.Jolly for the 1980 *Mineral Facts and Problems.* Washington, D.C.

U.S. Bureau of Mines. 1980. *Manganese.* A Chapter Preprint prepared by G.L. DeHuff and T.S.Jones for the 1980 *Mineral Facts and Problems.* Washington, D.C.

U.S. Bureau of Mines. 1980. *Nickel.* A Chapter Preprint prepared by N.A.

Matthews and S.F. Sibley for the 1980 *Mineral Facts and Problems*. Washington, D.C.

U.S. Bureau of Mines. 1982. *Mineral Commodity Summaries*. Washington,D.C.

U.S. National Oceanic and Atmospheric Administration. 1981. *Deep Seabed Mining: Report to Congress*. Washington,D.C.

Wijkman, P.M. 1982. UNCLOS and the Redistribution of Ocean Wealth. *Journal of World Trade Law*. 16(1): 27-48.

APPENDIX

SEABED MINING AND MINERAL TRADE PATTERNS

The preceding enquiry examines recent trends and the potential effects of seabed mining in three areas--mineral prices and production costs, the location of mining, and the benefits from mineral production and trade. This appendix, prepared after the original study was completed, extends that analysis by examining the possible impact of seabed mining on mineral trade patterns. The first section considers past trends in the patterns of trade for cobalt, copper, manganese and nickel; and the second the possible consequences of seabed mining on the future evolution of these patterns.

Recent Trends

A trade pattern reflects the geographic flow of a particular commodity in international trade, and is defined by a matrix whose elements measure the amount of trade between each exporting and importing country over a given period of time such as a year. For example, trade matrices prepared by Fischman (1980) for copper in 1976 and manganese in 1975, at several stages of production, are shown in the tables accompanying this appendix. Similar tables, based on the work of Hubbard (1975), portray the trade patterns for semiprocessed nickel in 1970 and refined nickel in 1972. Comparable tables for cobalt are not available, as the necessary information on international trade in this commodity has not been collected and published.

Historically, trade patterns have been largely ignored in the economic literature. This is in part because traditional international trade theory has focused primarily on comparative advantage and its underlying determinants. In the process, it has abstracted from transportation costs and the other factors affecting the choice of trading partners. There are, of course, exceptions. Location theory and a number of linear programming studies, for instance, have explicitly considered the flow of trade between particular countries. These efforts generally assume that the desire to minimize transportation costs dictates the pattern of trade.

In recent years, however, a number of studies (Dorr, 1975; Hubbard, 1975; Santos, 1976; Whitney, 1976; Tilton, 1966; and Demler and Tilton, 1980) have called into question the assumption that transportation costs constitute the only, or even the most important, determinant of trade flows of copper, manganese, nickel, and other mineral commodities (though not cobalt, as the necessary trade data are not available). These studies find that:

1. International ownership ties, and the multinational mining corporations responsible for these ties, greatly shape the pattern of mineral trade, often in directions inconsistent with minimizing transportation costs. Their influence is particularly apparent for mineral commodities at early stages of production, such as the ore and concentrate stage. This general conclusion is found to hold for trade in blister copper, manganese ore, and semiprocessed nickel, though somewhat surprisingly, not

for copper ore and concentrate.

2. Political blocs, such as the British Commonwealth, the French Community, and the commercial, cultural, and other ties they have created over the years among member countries, also influence the structure of mineral trade. In contrast to ownership ties, however, they are most important for trade in refined metal products, and have much less influence on trade at earlier stages of production. This general conclusion holds for blister and refined copper as well as for refined nickel. It may be valid as well for ferromanganese and refined cobalt, though existing studies have not examined these particular products.

3. The presence of a common border stimulates trade between neighboring countries, again primarily at the refined metal stage of production, significantly more than can be attributed to the relatively low transportation costs between such countries. Apparently, neighboring countries often share common business customs and possess other mutual attributes that stimulate trade between them. This particular determinant of trade patterns is significant for both refined copper and refined nickel, the two commodities found in seabed nodules whose trade patterns have been analyzed at the refined metal stage of production.

With respect to trends over time, some evidence exists to suggest that the influence of ownership ties has been declining. For several reasons, this finding is not particularly surprising. Over the last two decades, the mines and processing facilities of multinational mining companies in a number of developing countries have been nationalized, and are now operated by state-owned enterprises. Second, the nature of financing mineral ventures has changed over the last two decades. In the early years after World War II, most new projects were developed and entirely owned by a single major multinational mining corporation. The 1960s saw a shift towards project financing, where several firms collaborate in developing new ventures. They share the equity investment, and borrow a large portion of the total development costs from banks and other lending organizations. Such financial arrangements are likely over time to reduce the importance of intra-firm shipments in international trade. Finally, the influence of Japan on trade patterns has grown as mineral imports into that country have increased with its rapid economic development. Traditionally, Japan has relied less on ownership ties and more on long-term contracts than other industrialized countries to insure its import needs.

Focusing specifically on the four principal mineral commodities contained in seabed nodules, one finds the evidence supporting a decline in the importance of ownership ties more tenuous. For copper, no trend is discernable at the ore and concentrate stage (where, as noted earlier, ownership ties have not been significant) or at the blister stage (where ownership ties have been and remain important). Only at the refined metal stage has the influence of ownership ties waned over time (Whitney, 1976). In nickel, such ties shaped trade patterns in the early postwar period at both the semiprocessed and refined metal stages of production, and they have continued to do so in recent years (Hubbard, 1975).

One would also expect to find the influence of political blocs declining, reflecting the dissolution over the last thirty years of the major political empires. Surprisingly, the available studies provide little or no evidence supporting this expectation. Apparently, the ties established during the colonial period to encourage trade among member countries persist long after formal political bonds are severed. Likewise, the studies find little change over time in the importance of neighboring countries in stimulating trade. Where this factor was significant in the past, it remains so today.

For many mineral commodities, however, one important change has clearly occurred: the number of actual and potential trade partners available to both importing and exporting countries has increased. This development, in a number of cases, has reduced the vulnerability of countries to an interruption in trade with any particular partner. It has taken place, in part, because a number of new producers have entered mineral production--Cuba in cobalt, Indonesia and Papua New Guinea in copper, Gabon in manganese, and the Philippines, Dominican Republic, and Botswana in nickel. In addition, Japan and a number of European states have become important importers. In more recent years, rapid economic growth in some of the developing countries has made them significant importers as well.

This review of the available literature on mineral trade patterns does not suggest a rapid decline in the influence of international ownership ties, political blocs, and neighboring country effects on mineral trade patterns. Along with transportation costs, these factors are likely to shape the flow of mineral trade for some time into the future. In the process, they will continue to introduce a certain amount of rigidity into the structure of trade. On the other hand, if the past is a reliable guide to the future, the number of potential trading partners for many mineral commodities is likely to grow as new producers begin exporting and developing consuming states become important importers.

These expectations assume that past trends--or lack of trends-- will continue into the future, and that no major structural change will substantially transform the mineral industries. However, in the case of cobalt, copper, manganese, and nickel, seabed mining raises the possibility of such a structural change, and it is to the possible impacts on mineral trade patterns of this development that we now turn.

The Impact of Seabed Mining

The potential consequences of seabed mining for mineral trade patterns, as was the case for prices and production costs, the location of mining, and the distribution of costs and benefits, range over a wide spectrum of possibilities. At one extreme, trade patterns will obviously be completely unaffected if no seabed mining occurs during the 1995-2020 period. At the other extreme, trade patterns could be radically altered.

More specifically, seabed mining, if it occurs, will introduce new trade flows as production begins at new sources of supply. This should, at least initially, increase the number of actual and potential trading partners for importing countries, and so continue the trend in this direction that has characterized the last 30 years. Over the longer run, however, seabed mining could reduce, rather than increase, the geographic diversity of sources of mineral supplies, if seabed mining proves less expensive than many land-based sources of supply. Such a development would concentrate mineral production at sea and at a few high-quality land-based deposits, increasing the vulnerability of consuming countries to interruptions in trade from any particular source.

In addition, seabed mining may weaken the influence of political blocs and neighboring country effects on trade patterns if it replaces land-based production, as clearly neither of these factors will shape the flow of trade from seabed sources. Political ties, however, could still play an important role, though in a different way, as some consuming countries may be prepared to provide protected markets and in other ways to subsidize seabed production by their own firms or state enterprises in order to reduce dependence on foreign producers for needed mineral imports.

The rigidities introduced into trade patterns by international ownership ties could also be strengthened by seabed mining. This is particularly likely for trade at early stages of production--namely, in nodules--as each consortia planning to engage in seabed mining is expected to have its own land-based processing facilities to which it will ship its nodules.

Finally, it should be noted that the impact of seabed mining on trade patterns may vary considerably for different mineral commodities. For example, several mining operations at sea could greatly reduce the land-based production of cobalt, and in the process diminish the diversity of supply for this commodity. The same level of seabed production, by contrast, would have only a modest impact on copper mining from land-based deposits, and so would likely enhance, rather than reduce, the geographic diversity of sources for this commodity. Given the mineral composition of nodules and the relative size of the market for nickel, the impact on land-based nickel production and the consequences for its diversity of supply would be greater than in the case of copper, but less than in the case of cobalt. For manganese, seabed production even at a modest level will have a substantial impact on trade patterns if this mineral commodity is actually recovered. However, as is well known, many of the consortia contemplating the mining of seabed nodules are not now planning to extract and market the manganese they contain.

Table A-1. Estimated Distribution of World Trade in Copper Ores and Concentrates, 1976

(percent of total trade, metal content)[a]

Imp. \ Exp.	Canada	Philip-pines	Papua N.G.	Chile	Indonesia	Aus-tralia	Zaire	Norway	South[b] Africa	Other	Total
Japan	16.6	16.7	7.3	4.8	3.7	3.6	3.0			2.8	58.5
Germany (F.R.)	0.3		7.1	1.9	1.9			1.7	1.3	0.5	14.7
U.S.	3.2	1.2	0.1			0.2			0.3	1.4	6.4
Spain				2.1					0.3	1.6	4.0
Sweden	0.3	0.2						0.4		0.3	1.2
Belgium				0.4						0.8	1.2
USSR	1.0									0.2	1.2
Bulgaria				0.8						0.3	1.1
Other	1.5	1.5	0.4	3.0		0.3		0.1		4.9	11.7
Total	22.9	19.6	14.9	13.0	5.6	4.1	3.0	2.2	1.9	12.8	[c]100.00

Source: Fischman (1980), Table 3-9.

[a]Reported Cu content used wherever possible. For other oountries Cu content was estimated from gross weights.

[b]Including Namibia (S.W. Africa).

[c]Equates to total exports of 1,204,000 metric tons.

Table A-2. Estimated Distribution of World Trade in Unrefined Copper, 1976[a]

(percent of total trade)

Importers \ Exporters	Zaire	Chile	South Africa[b]	Peru	Germany (F.R.)	Zambia	Other	Total
Belgium	36.8	0.6	2.6	0.2	1.8		1.6	43.6
Germany (F.R.)		10.1	7.7	0.3			1.3	19.4
U.K.		3.6	0.7	0.8	2.8	0.2	0.6	8.7
U.S.		4.3	0.3	0.5		0.1	0.3	5.5
China (P.R.)		2.8		1.9				4.7
Japan		1.1	0.5	1.1		0.2	1.3	4.2
Yugoslavia		0.8				1.9	0.4	3.1
Spain		2.2		0.1			0.4	2.7
Other	1.4	2.5	1.0	0.6	0.1	0.4	2.2	8.1
Total	38.2	28.0	12.8	5.5	4.7	2.6	8.2	[c]100.00

Source: Fischman (1980), Table 3-10.

[a]includes secondary blister copper.

[b]includes Namibia (S.W. Africa).

[c]Equates to total exports of 825,000 metric tons.

Table A-3. Estimated Distribution of World Trade in Refined Unwrought Copper, 1976

(percent of total trade)

Exp. / Imp.	Zambia	Chile	Canada	Belgium	Peru	U.S.	Aus-tralia	Zaire	Germany (F.R.)	Yugo-slavia	Other	Total
Germany (F.R.)	2.8	3.0	1.3	1.9	0.1	0.8	0.5				4.1	14.5
U.K.	3.4	2.0	3.1	0.5	1.0	0.6	0.6		0.1		1.9	13.2
U.S.	4.4	2.2	3.0		0.8		0.1	0.1		1.5		12.1
France	1.8	2.0	0.8	3.3		0.7	0.4	0.3	0.3		1.3	10.9
Italy	2.6	2.5	0.5	1.4	0.2	0.5	0.1	1.0	0.4	0.2	0.8	10.2
Japan	4.3	1.1	0.4		0.2	0.2	0.2	0.6			0.2	7.2
Brazil		5.0	0.1		0.1	0.1					0.1	5.4
Belgium	0.6	0.4	0.5		0.7		0.4	0.3	0.2		0.6	3.7
Sweden	0.6	0.4	0.4	0.4		0.2	0.2				0.3	2.5
Neth.		0.2	0.1	0.7	0.2	0.2	0.1		0.2		0.5	2.2
Other	4.4	2.0	0.6	2.5	1.1	0.3	0.1	0.3	1.1	0.1	5.6	18.1
Total	24.9	20.8	11.0	10.7	4.3	3.6	2.7	2.6	2.3	1.8	15.3	[a]100.00

Source: Fischman (1980), Table 3-11.

[a]Equates to total exports of 2,781,700 metric tons.

Table A-4. Estimated Distribution of World Trade in Manganese Ore, 1975[a]

(percentages based on Mn content)[b]

Exp. / Imp.	South Africa	Gabon	Aus-tralia	Ghana	Zaire	Morocco	Brazil	Mexico	India	Undis-tributed or other	Total
U.S.	2.1	5.5	1.9		0.2		7.0	0.5			17.3
Japan	14.0	2.1	7.8	0.5	0.1	0.6	0.2	1.1	4.7	2.2	33.5
Germany (F.R.)	3.7	0.3	1.0			0.1	0.5			0.3	5.9
France	5.1	6.4				0.3		0.4			12.3
U.K.	0.7	0.7		0.1		0.2	0.9			0.3	2.9
Italy	1.5	1.3					0.4			0.7	4.0
Neth.										0.5	0.5
Bel./Lux.	1.6	0.4	0.1		0.9		0.2			0.5	3.7
Sweden		0.1								0.1	0.3
Spain	1.7	1.4	0.3	0.6			0.6			0.3	4.9
Norway	3.5	3.1	1.2	0.8	0.2		2.8			0.4	12.1
Canada		0.9			0.2		0.4			0.2	1.7
Other										0.7	0.7
Total	33.9	22.3	12.4	2.1	1.6	1.3	13.0	2.1	4.7	6.4	[c]100.0

Note: Detail may not add to totals, owing to rounding.

Source: Fischman (1980), Table 3-3.

[a]Represents total imports of developed countries (87 percent of total world imports).

[b]Includes ores with 10 percent or greater manganese content.

[c]Equates to imports of 4,003,000 metric tons.

Table A-5. Estimated Distribution of World Trade in Ferromanganese, 1975[a]

(percentages based on gross/net quantities[b])

Exp. / Imp.	France	Norway	South Africa	Bel./ Lux.	Germany (F.R.)	Japan	U.S.	Spain	India	Other	Total
U.S.	10.2	2.0	10.7	0.2	0.1	8.3		0.8	0.4	1.5	34.2
Germany (F.R.)	4.5	5.5	0.9	1.1		1.2	0.3			1.3	14.8
Italy	5.6	0.5	3.7	0.4	0.6			0.6		0.5	11.8
Bel./Lux.	4.0	1.6	0.2		1.3	0.4					7.4
France		0.1			0.8						0.9
Neth.	0.7	1.5	0.2		0.3	1.0					3.6
U.K.	0.6	5.2	3.1			0.1				0.3	9.3
Sweden		3.8	0.2				0.3				4.3
Denmark		0.8									0.8
Austria		1.5	0.2		0.2						1.8
Canada	0.2			0.5	0.3	0.3	1.9				3.2
Turkey						0.5			0.7		1.2
Undetermined and other	0.2	2.4	1.2	2.0		1.0					6.8
Total	25.9	24.9	20.4	4.2	3.5	12.7	2.5	1.4	1.1	3.5	[c]100.0

Note: Detail may not add to totals, owing to rounding.

Source: Fischman (1980), Table 3-4.

[a]Represents total ferromanganese trade of "developed" countries. Includes developed countries' trade to and from "developing" and Eastern European countries, if applicable.

[b]Average manganese content varies only within narrow limits (75 to 78 percent).

[c]Equates to total imports of 1,030,000 metric tons.

Table A-6. Estimated Distribution of World Trade in Semiprocessed Nickel, 1970[a,b]
(percent of total trade, metal content)

Imp. \ Exp.	Canada	Indonesia	New Caledonia	Australia	Other[c]	Total
U.K.	15.8					15.8
Norway	18.4[d]					18.4
Japan	3.9		45.8			49.7
France		5.5	3.6	e		9.1
Canada			1.7	4.7		6.4
Other			0.6			0.6
Total	38.1	5.5	51.7	4.7		100.0[f]

Source: Hubbard (1975), Table 2.

[a]Trade involving the socialist countries, including Cuba, is excluded.

[b]Semiprocessed nickel, measured in terms of metal content, encompasses ore, matte, concentrate, and oxide.

[c]Brazil, Zimbabwe, South Africa, Finland, Burma, and Morocco may have exported semiprocessed nickel in 1970; however, little is known about these possible trade flows except that they were very small.

[d]This material was refined and then reexported.

[e]Japan imported some nickel concentrate from Australia. The amount is unknown but presumed to be small.

[f]Total trade equalled 230 thousand metric tons of contained nickel.

Table A-7. Estimated Distribution of World Trade in Refined Nickel, 1972[a,b]
(percent of total trade)

Imp. \ Exp.	Canada	Norway	U.K.	France	New Caledonia	Australia	South Africa	Other	Total
U.S.	31.6	4.8	1.4	0.6	3.2	0.2	1.0	0.1	42.9
Germany (F.R.)		2.1	2.5	1.5		2.2	1.4	0.8	10.5
Belgium-Luxembourg	0.2		1.6	0.2			0.1	0.1	2.2
Netherlands		1.5	0.5					0.6	2.6
France	0.1	0.6	2.0		9.8	0.2	0.1	0.4	13.2
Italy	0.4	0.7	1.2	0.9		0.2	0.3	0.6	4.3
U.K.	3.1	1.1		0.1		1.3	0.1	0.2	5.9
Sweden	0.1	1.8	1.3	1.3		0.5	0.5	0.2	5.7
Japan	1.1	0.8	0.2					0.1	2.2
Other	3.6	1.4	1.7	1.0	1.5	0.1	0.3	0.9	10.5
Total	40.2	14.8	12.4	15.6	14.5	4.7	3.8	4.0	100.0[c]

Source: Hubbard (1975), Table 9

[a]Refined nickel, measured in terms of metal content, includes all products, including ferronickel, at the last stage before industrial use.

[b]Trade involving the socialist countries is excluded.

[c]Total trade equalled 272,009 metric tons.

APPENDIX REFERENCES

Demler, F.R., and J.E. Tilton. 1980. Modeling International Trade Flows in Mineral Markets. Pages 85-120 in: *Commodity Markets and Latin American Development: A Modeling Approach*, edited by W.C. Labys, M.I. Nadiri, and J.N. Del Arco. Cambridge, Massachusetts: Ballinger.

Dorr, A.L. 1975. International Trade in the Primary Aluminum Industry. Unpublished PhD Dissertation. University Park, Pennsylvania: Department of Mineral Economics, Pennsylvania State University.

Fischman, L.L. 1980. *World Mineral Trends and U.S. Supply Problems*. Research Paper R-20. Washington, D.C.: Resources for the Future.

Hubbard, D.A. 1975. Nickel in International Trade. Unpublished MS Thesis. University Park, Pennsylvania: Department of Mineral Economics, Pennsylvania State University.

Santos, T.M. 1976. International Trade in Iron Ore: An Economic Analysis of the Determinants of Trade Patterns and Comparative Advantage. Unpublished PhD Dissertation. University Park, Pennsylvania: Department of Mineral Economics, Pennsylvania State University.

Tilton, J.E. 1966. The Choice of Trading Partners: An Analysis of International Trade in Aluminum, Bauxite, Copper, Lead, Manganese, Tin, and Zinc. *Yale Economic Essays* (Fall):416-74.

Whitney, J.W. 1976. An Analysis of Copper Production, Processing, and Trade Patterns, 1950-1972. Unpublished PhD Dissertation. University Park, Pennsylvania: Department of Mineral Economics, Pennsylvania State University.