# THE LOCATION OF MINERALS PROCESSING

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## FOREWORD

As part of its research, the Mineral Trade and Markets Project is examining trends in the major metal industries since 1950. As now envisaged, this study will contain four substantive chapters. The first, a draft of which is available as an IIASA working paper (WP-83-91), reviews changes in the location of metal mining and identifies the important determinants responsible for these changes. The second chapter focusses in a similar manner on geographic shifts in metal consumption, while the third investigates trends in the location of processing. The fourth examines the role of transportation costs, political blocs, international ownership ties, and other factors that influence the choice of trading partners and introduce rigidities into international trade flows.

This working paper is a preliminary version of the third chapter concerned with the location of processing. It will be revised before publication, and is being circulated at this time to elicit comments, criticisms, and suggestions for improvement.

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# ABSTRACT

A popular perception has arisen that the mineral production of developing countries is too often exported in unprocessed form, thereby depriving the host country of the value-added and benefiting the developed country importer. The validity of this allegation and possible explanations for the location of minerals processing is the subject of this working paper. An examination of the patterns and trends in the location of processing for aluminum, copper, iron, nickel, tin and zinc, up to the refined metal stage, reveals that developing countries are processing a larger proportion of their mine output today than 30 years ago. Despite significant progress, the developing countries as a group are processing less than 50 percent of their ore production, with the exception of tin and copper. When the major ore producers from all country groups are considered, the data reveal that only two commodities, tin and alumina, exhibit a trend toward greater domestic processing. Thus, the pattern of exporting minerals in unprocessed form is not confined to developing countries, but is exhibited by a number of developed countries, particularly Canada and Australia.

To explain this pattern of behavior the chapter offers three plausible explanations. The first contends that economic factors, such as comparative costs, are responsible for the location of processing. The second explanation attributes the location to primarily political factors, such as tariff barriers or government subsidies. The third explanation, though not entirely independent of the other two, emphasizes the dynamic nature of the location of processing by accounting for the effect of the historical legacy.

The analysis demonstrates that comparative advantage at one stage of processing does not guarantee comparative advantage at subsequent stages. Proximity to ore production is not necessarily more advantageous than locations with an abundant supply of complementary inputs, such as energy, or proximity to markets. Declining transportation costs have reduced the diseconomies of processing at greater distances from the mine. Other economic considerations, as well as the impact of public policy and the historical legacy differ by commodity and over time.

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## INTRODUCTION

Minerals processing occurs in a variety of locations, ranging from those close to the mine site to those with proximity to commercial centers and including some third party countries that are neither major producers nor major consumers but appear to possess a comparative advantage of another type. A popular perception has arisen that developing countries in particular do not process an optimal share of their ore production prior to export. This situation has warranted international attention. The strategy of downstream processing of developing country exports of primary commodities has been the subject of such global resolutions as the U.N. General Assembly's Program of Action on the Establishment of a New International Economic Order, the Lima Declaration of UNIDO's Second General Conference, and the International Development

Strategy of UNCTAD. (Wall, 1979).

Downstream processing can provide significant benefits. The value added by processing contributes to the country's export earnings and to government revenues. The processing industry provides employment opportunities. Further domestic processing may enhance the country's control over the minerals sector of the economy and thereby permit the country to reap greater economic and social benefits from the minerals sector. In another light, minerals processing is not viewed as an end in itself; rather, it is desirable for its contribution to further economic development and diversification. This line of reasoning maintains that local industries should arise to supply the processing industry with required inputs or to use the output to make finished products. Economic nationalism provides still another justification for domestic processing and is reflected in the idea that mineral exporting developing countries should be more than the "hewers of wood and the drawers of water" for the developed capitalist economies (Balogh, 1978). This concern is not strictly limited to developing countries but is also expressed to a degree by Canada, itself a major exporter of minerals in both processed and unprocessed form. The non-renewable nature of minerals contributes to economic nationalism, engendering the attitude that mineral resources must be used to foster domestic development or conserved for future generations, rather than exploited for the benefit of consumers in a foreign country.

Interest in processing is not limited to ore producing countries. Those countries whose processing industries are dependent on imported raw materials, seek a dependable supply of quality inputs at a reasonable price while maintaining some flexibility to react to changing economic circumstances. The final consumer is primarily concerned with obtaining the product at lowest possible costs, and indirectly with the impact of the location of processing on that objective.

Finally, questions concerning the location of processing are important for the larger study, of which this chapter is a part, because it determines the stage of production at which trade occurs. For our purposes, the scope is limited to the treatment of ores up to the refined metal stage.

The next section presents data on the portion of ores that are processed domestically. The data help to answer the question: what progress have developing country mineral exporters made in acquiring downstream processing, over time and for which metals. Their progress is compared with that of developed country mineral exporters, such as Canada and Australia. The chapter then examines the major factors influencing the location of processing. Three explanations for the observed behavior are described. The first contends that economic factors, such as comparative costs, are primarily responsible for the location of processing. The second explanation attributes the location to primarily political factors, such as tariff barriers or government subsidies. The third explanation, though not entirely independent of the other two, emphasizes the dynamic nature of the location of processing. For example, historically a lag appears between development of mine output and smelting capacity, during which time ores are exported. Upon mine exhaustion, existing processing capacity is still usable and relies upon imported ores from a new mining area. The final section of the chapter evaluates each explanation in light of the evidence and draws conclusions about the determinants of the location of processing.

## PATTERNS AND TRENDS IN MINERALS PROCESSING

Table 1 presents the amount of ore processed by developing countries as a group, as a percent of the ore mined by developing countries. The table shows that developing countries are processing a larger proportion of their mine output today than 30 years ago, with the single exception of blister copper. Nevertheless, the developing countries still process a relatively low percent of their ore production, less than half, with the exception of tin and copper. Similar tables for the developed countries and socialist countries would show ratios consistently in excess of one for the developed countries, and almost as consistently equal to one for the socialist countries. Table 2 presents the percentage of ore processed in the country in which it is mined, including all major producers from all country groups. Only two commodities, alumina and tin, exhibit a trend toward greater domestic processing. A comparison of Table 2 with Table 1 indicates the degree of success that developing countries have experienced relative to ore producing countries in general, in processing greater amounts of their mineral output. The pattern varies significantly by commodity, and for each commodity a look behind the aggregate data merits attention. Appendix tables 1 through 8 provide production data by commodity, by country, for selected years from 1950 through 1980.

Table 1.Ore Processed by Developing Countries as a Percent of Ore Mined by Developing Countries

| Commodity | 1950 | 1960 | 1970 | 1980 |
|---|---|---|---|---|
| Alumina[a] | NA[b] | 15 | 33 | 39 |
| Aluminum[a] | 1 | 4 | 9 | 20 |
| Blister Copper | 87 | 90 | 88 | 78 |
| Refined Copper | 50 | 48 | 61 | 64 |
| Pig Iron | 38[c] | 19 | 16 | 31 |
| Nickel[d] | 9 | 17 | 27 | 44 |
| Primary Tin | 47 | 65 | 78 | 94 |
| Refined Zinc | 17 | 28 | 35 | 48 |

Table 2.Ore Processed by Major Ore Producing Countries[e] as a Percent of Ore Mined

| Commodity | 1950 | 1960 | 1970 | 1980 |
|---|---|---|---|---|
| Alumina[a] | NA[b] | 40 | 52 | 57 |
| Aluminum[a] | 35 | 32 | 27 | 20 |
| Blister Copper | 89 | 87 | 85 | 77 |
| Refined Copper | 74 | 69 | 77 | 73 |
| Pig Iron | 74[c] | 57 | 49 | 48 |
| Nickel[d] | 63 | 60 | 57 | 64 |
| Primary Tin | 44 | 59 | 70 | 81 |
| Refined Zinc | 61 | 61 | 58 | 59 |

*Notes:*

[a] To account for the non-metallurgical uses of bauxite, bauxite production was reduced by ten percent before the ratio of alumina production to bauxite production was calculated. To account for the non-metallurgical uses of alumina, bauxite production was reduced by an additional five percent before the ratio of aluminum production to bauxite production was calculated.

[b] NA indicates data are not available.

[c] Includes ferroalloys.

[d] Includes primary nickel and nickel contained in ferronickel, nickel oxide sinter and copper-nickel alloys smelted directly from ores.

[e] Major ore producing countries represent all countries with mine output equal to, or greater than, one percent of world production.

Source: Appendix Tables 1 through 8; Tilton (1983) *Comparative Advantage in Mining.* Appendix Tables 1a-f. IIASA Working Paper No. WP-83-

*Aluminum.* The transformation of bauxite into aluminum metal involves two stages. In the first stage bauxite is refined into aluminum oxide, commonly called alumina. In the second stage smelting of the alumina removes the oxygen and produces aluminum metal. Developing country bauxite producers have been much more successful in acquiring alumina processing capacity than aluminum smelters. Data for alumina production in 1950 are not available, reflecting the lack of an established market for alumina at that time. In 1955, six percent of their bauxite was processed into alumina domestically; the corresponding number for 1980 is 39 percent. Between 1970 and 1980 almost all major bauxite producers, with the notable exception of Guinea, increased their share of alumina processing. Surinam now refines 70 percent of its bauxite and Jamaica 40 percent. Australia had refined 50 percent in 1970 and increased the share to 60 percent by 1980. For aluminum smelting, not only do developing countries process a much smaller share of their alumina into aluminum, but the aluminum smelting that does occur does not take place in the countries that are the largest bauxite producers. For example, Guinea and Jamaica produce no aluminum; and Surinam processed only six percent of its bauxite into aluminum in 1980. The developing countries with aluminum smelters are those with the larger domestic markets, such as Brazil and India. In addition, Venezuela and more recently Bahrain, have established aluminum smelting capacity, in spite of the fact that they have no bauxite production and consume only a small percent of their aluminum output.

The pattern exhibited by the developing countries is also representative of the developed countries. Australia, the world's largest bauxite producer, processes only five percent of its bauxite into aluminum. Greece, the second largest bauxite producer among the developed countries, processes 20 percent of its bauxite into aluminum. Only 20 percent of the aluminum produced in 1980 was smelted in the same country in which the bauxite was mined, down from 35 percent in 1950. Aluminum smelting is more likely to occur in countries with large domestic markets, such as the U.S., Japan and the Federal Republic of Germany. Two significant exceptions are Canada and Norway who smelt most of their aluminum for export.

For the socialist countries data limitations permit only a few observations. Between 1950 and 1980 the socialist countries have developed the capacity to process quantities of alumina and aluminum in excess of their bauxite production. Over the past two decades Hungary has increased its share of alumina processing from 50 percent to nearly 80 percent of its bauxite production. Despite rapid growth in both bauxite and alumina production, Hungary's aluminum production has remained fairly limited. This situation reflects the Hungarian-Soviet Alumina-Aluminum Treaty of 1962, whereby smelting capacity for Hungarian alumina was established in the U.S.S.R. to exploit surplus hydroelectric power there. As a result, the U.S.S.R. increased its smelter capacity at a faster rate than its ore production.

*Copper*. The transformation of copper ore to refined copper metal requires the concentration of the ore (20-40 percent Cu), the smelting of the concentrate to produce blister copper (96-99 percent Cu), and then the refining of the blister to produce copper more than 99.9 percent pure. An international market exists for each of the products: concentrates, blister and refined copper. Developing countries have throughout the period smelted most of their concentrates domestically; however, since 1960 a downward trend has developed. In 1980 only 78 percent of copper ore produced in developing countries was smelted, compared to 90 percent in 1960. While it is true that some traditional producers, specifically Chile and Zaire, are smelting a slightly smaller portion of their mine output, the primary cause for the downward trend lies with the relatively new mining areas opened up in the Philippines, Papua New Guinea, and Mexico. The Philippines completed the construction of their first smelter-refinery complex in 1983.

The developing countries exhibit a general upward trend in percentage of ores processed to the refined copper stage. Zambia now refines 100 percent of its ore production. Peru has made substantial gains in refining its ore domestically, from 16 percent in 1960 to 63 percent in 1980. Chile exhibits a similar, though less dramatic, trend from 42 percent in 1960 to 76 percent in 1980. Of the major developing country producers only Zaire processes a lower percentage today than formerly. Zaire's refining capacity has remained almost unchanged since 1960, while its mine output grew by over 50 percent. South Korea and Taiwan have recently developed processing industries. While their capacity is not large compared to the developed countries, it is an indication that developing countries without domestic ore production have acquired processing capability.

For developed countries the general trend has been to maintain smelting capacity in excess of the amount required to process domestic ores. Japan and the Federal Republic of Germany maintain a large smelting capacity despite the lack of a substantial domestic copper mining industry. In 1950 and 1960, the U.S. smelted more ore than it mined; but for the two later years of the study, the U.S. smelted slightly less than it mined. Canadian smelter output as a percentage of mine output fell significantly from 90 percent in 1960 to 66 percent in 1980, due primarily to the opening up of new mines in British Columbia, far from existing processing facilities.

In developed countries refining capacity is large relative to ore production, in part because they produce a substantial amount of refined copper from old scrap. In 1980, the U.S. produced 1,686 thousand tons of refined copper, of which 28 percent was produced from scrap. Nevertheless, the U.S. refined less copper in 1980 than in 1970. Belgium maintains the world's seventh largest refinery capacity, relying primarily on imports.

The socialist countries smelt all their copper ores, almost exclusively within the country of origin. Refined copper output exceeds smelter output in the U.S.S.R. by approximately 25%, which probably reflects the role of scrap and not the effect of imports. Poland, the second largest copper ore producer among the socialist countries, smelts and refines virtually all its ore domestically. China refined almost twice as much copper as it smelted in 1980.

*Iron*. Data for pig iron production are used to identify where iron ore is processed. Unfortunately the data do not account for iron ore that is treated by the direct reduction method of ironmaking. While the magnitude of direct reduction is still not large, it is relatively more important for developing countries. Hence, a slight underestimation of the quantity that developing countries process results.

In 1950 the developing countries were not large iron ore producers, accounting for less than 10 percent of world output. In 1955 and 1960 they processed about 20% of their iron ore into pig iron, attributable largely to India and Brazil. Between 1960 and 1970 their iron ore production more than doubled, and the percentage smelted locally fell. By 1980, 31 percent of their ore was being processed in developing countries. Mexico had joined the ranks of significant developing country producers.

The early pattern of iron production consisted of the United States and the larger, developed countries of Europe as the major producers, relying primarily on domestic ore and ore imports from Sweden. Mining, processing and consuming took place within one country or in close geographic proximity. By 1960 Canada and Venezuela had become important ore suppliers for the U.S. From the largest iron producer in 1960, the U.S. fell to third place by 1980 and actually produced less iron in 1980 than it had a decade earlier. By 1980 Japan had become the second largest iron producer, behind the U.S.S.R. Japan relies entirely on imports for its supply of iron ore. Australia is a major supplier for the Japanese industry. Australia processed only 13 percent of its iron ore in 1980. Canada, Sweden and South Africa also produce much more iron ore than their domestic iron industry consumes. Less than half the iron ore mined in 1980 was processed into pig iron domestically, and this trend over the last 30 years has been downward.

The Soviet Union processes about 80 to 90 percent of its iron ore domestically, while Poland and Romania maintain an iron industry without significant domestic iron ore production. The result is a balance between ore production and pig iron output for the socialist countries as a whole.

*Nickel.* Nickel processing results in a variety of commercial products. For our purposes, in addition to primary refined nickel, the data include the nickel content of ferronickel, nickel oxide sinter and copper-nickel alloys smelted directly from ores. These intermediate, processed products are used directly by the steel industry. Between 1950 and 1960 New Caledonia was the only developing country to process any nickel. From 1970 onwards Cuba processed half its mine output. During the 1970s the Philippines and the Dominican Republic became ore producers and simultaneously built processing capacity. As a whole, the developing countries processed 44 percent of their ore in 1980.

While the developed country nickel ore producers do process a larger share of their ore than the developing countries, a significant amount is processed in developed countries without nickel mines. In fact, nickel processing is less concentrated than nickel mining. For example, in 1980 Australia processed only half of its output; and over the period Canada has processed between 60 and 80 percent. Among the ranks of the important processing countries that lack nickel mines are the U.S., the U.K., and Norway in the early years, joined later by France, and then more recently joined and overtaken by Japan.

Over the latter half of the period covered by the study, the socialist countries began to process more than they mined, due primarily to the U.S.S.R. However, if Cuba is included with the socialist countries a balance between mine output and processed output results because the U.S.S.R processes the ore that Cuba does not process domestically.

*Tin.* The role of developing countries in tin refining presents a dramatic contrast to the other metals under study. Malaysia is the largest processor over the entire period. In addition to refining all its domestic ore production, Malaysia also processed imported ore over the entire period. By 1970 Thailand and Nigeria were also processing 100 percent of their ore. Indonesia built a smelter in 1967 and by 1980 was processing almost all its ores domestically. Bolivia has embarked on a policy of more domestic processing and was able to smelt 50 percent of its ore by 1980. The developing countries as a group smelted 94 percent of their ore output in 1980.

The role of developed countries in tin processing has been one of continual decline since 1950. The only developed country with significant ore production, Australia, processes only half of its ore. The U.S., the U.K., the Netherlands and Belgium were the four largest processors in 1950 after Malaysia. From a position in 1950 of producing over 50 percent of the world's refined tin, these four developed countries' share of output fell to 6 percent by 1980.

*Zinc.* The developed countries dominate the zinc smelting industry just as they do the zinc mining industry. Nevertheless the developing countries managed to process almost 50 percent of their ore in 1980. Mexico's processing industry now treats 60 percent of the domestic ores. While Peru's mine output has grown over the past decade, its smelter capacity has remained static. Although small relative to world output, both Brazil and the Republic of Korea have smelting industries that are more than sufficient to treat domestic ores.

Among the developed countries processing capacity is widespread. Canada processes about half its output, and Australia processes a slightly higher percentage. The only developed country zinc ore producers without smelters are the Irish Republic and Sweden. Enough concentrate exports are available to support processing in just about every other European country. Japan smelts about three times the amount that it mines. The U.S. zinc smelting industry has been on the decline, following the trend of ore production. In 1980 U.S. zinc metal output was only 40 percent of what it was in 1970.

The review of trends in processing raises a series of questions, such as: why do even developed country ore producers, such as Canada and Australia, often export large amounts of metal in concentrate form; what is responsible for the downward trend in the proportion of copper smelted by developing countries; what is the cause for the decline in the position of the U.S. processing industry; is proximity to markets more important for some metals than for others. Having established *where* processing takes place, it is now appropriate to investigate *why*. The next section examines the theories that attempt to explain this behavior.

## DETERMINANTS OF THE LOCATION OF PROCESSING

This section presents a brief theoretical discussion of the determinants of the location of processing. The determinants fall into three categories: those that are economic in nature, those that are political, and those that are the result of the historical legacy of past activity. As each category is described in turn, some interrelationships will become apparent.

### Economic Determinants

The economic objective behind the choice of location for processing is to minimize costs. Factors influencing costs include input availability, economies of scale, transportation costs and marketing costs.

Input availability at a competitive price is a necessary prerequisite for processing. This argument follows the line of reasoning of the factor endowment theory discussed in Chapter 2.[1] In addition to the mineral raw material, inputs include labor, energy, technology and capital. As was also mentioned in Chapter 2, most inputs are mobile; however, mobility is rarely cost-free. The labor input required for most mineral processing operations is small. Energy on the other hand represents a large part of the cost of most processing operations. While coal and petroleum are easily transported, hydroelectric power is much less mobile. Technology is frequently embodied in the capital input. Tech-

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[1] Tilton (1983) is the draft of the second chapter of the larger study of which this working paper is a part.

nology was once solely the possession of multinational mining companies; however, this is no longer true (Radetzki, 1982A and UNCTAD 1978). Technology can be purchased and the necessary amounts of capital have become so large that frequently even the multinational mining companies engage in debt financing and joint venture.

The availability of capital affects the choice of location in yet another way. Larger absolute amounts of capital are required for a greenfield facility than for the expansion of an existing, or brownfield facility. Furthermore, the capital cost per unit of output is frequently lower for the brownfield facility. The costs of production from any incremental capacity must compare favorably with those from existing facilities, whose capital costs may be already partially or fully amortized. Since "sunk costs are sunk", existing facilities will continue in operation when price does not cover total costs so long as variable costs are covered. As a result, the capital investment involved prevents the processing location from changing quickly especially when overcapacity exists or little growth in demand is expected. In that case, further investment in processing is not financially attractive.

Related to input availability is the need to amass a sufficient quantity of inputs to operate a facility of the minimum efficient scale (MES). Otherwise, the firms must choose between building a smaller, less efficient plant or operating a MES facility at less than the optimal capacity. Economies of scale determine how significant the cost disadvantage is for the small producer. Where a range of technological choice exists, the impact of a smaller scale operation may be very slight. In addition, a cost disadvantage due to smaller scale may be counteracted by a cost savings arising from some other characteristic of the location.

Transportation costs encompass both the costs of assembling the inputs and the costs of delivering the output to market. The declining trend in transportation costs, that began long before the period covered by this study, continued to exert considerable influence over the market scope for minerals during the 1950s and 1960s. Iron ore from South America can successfully compete in the mid-western region of the United States with domestically produced iron ore, basically because the higher grade of the foreign ores is more than sufficient to compensate for the higher transport costs incurred. Over the past decade the rise in energy prices, specifically bunker fuel, has temporarily arrested the downward trend in shipping costs.

In minerals processing, significant weight reductions frequently take place, resulting in some transport cost savings. For example, smelting a ton of copper concentrate with a 28 percent Cu content to produce blister with a 98 percent Cu content results in a weight reduction of more than 70 percent. In contrast, the weight reduction from refining the blister copper to a 99.99 percent level of purity is quite small. Over the period a relatively greater decline in shipping costs has occurred for the bulk commodities, such as iron ore and bauxite. A result is that processing at distances from the mine has become relatively more economical. The greater decline in bulk shipping costs may be attributed to improved economies in loading and handling procedures, and to the use of larger vessels. This turn of events further frustrates the developing countries in their desire to increase domestic processing and has resulted in allegations of monopolization in the shipping industry and discrimination against developing countries (UNCTAD, 1981A). Counter arguments include the rationale that shipping costs are higher for processed goods because processed goods are of higher value and shipping costs represent a smaller proportion of that value. Hence the price elasticity of demand for transport is likely to be lower for processed goods than for unprocessed goods.[2] While the general trend in shipping costs has aided the mineral exporting countries, the relatively greater decline in bulk shipping costs may discourage further processing near the mine in favor of processing near consuming centers.

The final economic factor is the role that marketing plays in the location of processing. Marketing skills could be viewed simply as another input, a specialized type of skilled labor. The reason for treating this separately here is to focus attention on the structural characteristics of the market that can affect the location of processing. For example, does an arm's-length market exist for the product at the proposed stage of processing, or is this market foreclosed due to vertical integration or long-term contracts? Some mineral industries exhibit a high degree of vertical integration. While this factor alone need not be a barrier to entry, it may require that a new producer integrate forward more than one stage of the processing chain, thereby raising the capital costs and generally complicating the investment decision. Allegations of restrictive business practices have arisen due to a high degree of vertical integration. For example, the vertically integrated firm can set transfer prices with the objective of minimizing tax liability rather than

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[2] For further, though still inconclusive, discussion the interested reader is referred to UNIDO, 1981, UNCTAD 1981A and 1981B.

representing the true market value. A nonintegrated firm would be unable to compete at the transfer price.

Long-term contracts have arisen as an alternative to vertical integration as a way of guaranteeing a steady supply of inputs, and in response to the need to raise very large amounts of capital from diverse sources. In both ways, long-term contracts seek to reduce or transfer some of the commercial risk. Long-term contracts need not bias the location of processing if they merely act to bring together buyers and sellers in the market. Nevertheless, where long-term contracts are widespread, the remaining market may be so thin that its clearing price is unrepresentative of the market as a whole. In addition, the duration of long-term contracts limits the flexibility of a firm attempting to enter a downstream processing activity either because their output is already committed or because potential customers are. Some flexibility remains, however, because long-term contracts do not customarily cover 100 percent of the firm's requirements.

Three further factors influence the marketing aspect of location: domestic demand, byproducts, and growth in the industry. The existence of a domestic market facilitates domestic processing because of potential savings in transportation costs and an ability to respond more quickly to changes in the market. A number of factors considered above, economies of scale, transportation costs, and a domestic market also apply to byproducts. The revenue from sales of byproducts encourages a processing location close to consuming centers if no market exists at alternative locations and if transportation costs are prohibitive. Finally, when the industry experiences a period of growth all the problems associated with marketing are diminished, whereas a period of stagnation exacerbates these problems.

## Political Determinants

Government policies to encourage domestic industry are not uncommon, and in the minerals industries politics can sometimes play a more important role than economics. Justification for government intervention ranges from the necessity to correct a market imperfection, to the argument that economic efficiency is less important than other objectives, such as income redistribution, employment, or national pride. For example, tariffs can be used simply to protect domestic industry or to compensate for unfair trade practices. In some countries tariff rates on raw materials are zero or very low, and tariffs for processed materials escalate with the degree of processing. In this case, the effective rate of protection afforded the domestic processing industry is higher than the nominal rate; and conversely, the barrier faced by the exporter is higher. Exporting countries can retaliate by enacting export duties on unprocessed materials. These duties seek to neutralize the disadvantage of exporting processed goods. Other facets of the tax system in addition to tariffs are used to encourage domestic processing.

Governments subsidize uneconomic capacity in a variety of ways, including low cost energy or low-interest loans. Motivations include regional development objectives, national security or the need to preserve jobs. Some countries, such as Japan, have adopted a series of policies to permit large processing industries to flourish while dependent on imported materials.

Not all government policies favor domestic processing. Environmental regulations are especially onerous for the minerals processing industry. An alternative to compliance with domestic environmental regulations is to move the activity abroad. In this manner, developed countries can pursue the option of exporting their most polluting mineral processing activities (Radetzki, 1982A).

Over the period of the study, many developing countries have become politically independent and have developed the political infrastructure necessary to exercise a large amount of control over their domestic economy in general and over foreign investment in particular. Along the way, some countries, in which the minerals sector played a major economic role, nationalized mineral operations owned by multinational mining companies. The nationalizations and the increasing sophistication of the developing countries in pursuing their economic and political objectives have changed the rules of the game for the traditional investor in the minerals industry. The result is greater uncertainty and higher perceived risk that may influence the choice of location for processing.

## Historical Legacy

A review of the historical pattern of processing aids our understanding of the current situation and underscores the fact that the situation is not static. At one time, mining, processing and consumption took place in close geographic proximity. It was natural to first explore close to home. Furthermore, transportation costs encouraged processing and consumption near the location of the natural resource. Over time the exhaustion of local deposits led to exploration further afield. While mining in unfamiliar locales was accepted as an undeniable necessity, the need to relocate processing facilities was not always apparent. The useful life of the established processing capacity frequently exceeded the mine life. In the event that new capacity was required, locations close to home were favored for two reasons: the ability to exercise control more easily, and the desire to minimize political risk. The shifts in processing came more slowly than those in mining.

Over time, a country's minerals industry is likely to pass through several stages. Observations of this behavior in Europe led D.F. Hewett to hypothesize a general rule in 1929. Depicted in Figure 1, this model predicts five stages that a nation experiences in regard to a mineral industry. In the first stage mine output is exported. As the number of mines increase in stage two, a smelting industry takes root (stage three) and ore exports drop off. The fourth stage represents the pattern of metal production. As mine output declines due to exhaustion, imported ore provides the feed for domestic smelters (stage five). Hewett warns that the order of stages need not be invariable over a wide range of history, and that the successive relation of the peaks is more important than the relative heights of the curves. The model is particularly applicable to countries with domestic fuel supplies and the endurance of smelting capacity after mine exhaustion "depends upon the local fuel and power supplies and the maintenance of competitive technique" (Hewett, 1929, p. 90).

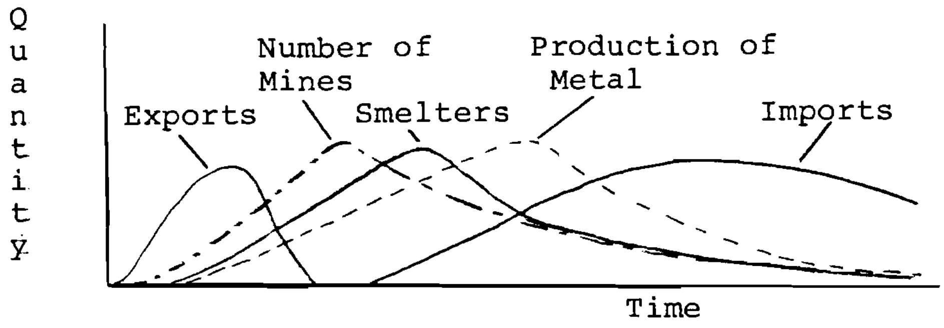

Figure 1. Stages of the Metal Industries. (From D.F. Hewett, "Cycles in Metal Production," 1929, p.89.)

A simplified interpretation of the Hewett model for our purposes would stress two stages. After mining begins, a period of ore exports is common due to a delay in building processing facilities. Upon exhaustion of the mines, a period of ore imports is common due to the continued viability of the processing industry. The model is based primarily on behavior observed in Europe, and covers a time frame of an order of magnitude of 100 to 200 years. Hewett provides some evidence from U.S. behavior, reminding us that ore from many early copper, zinc, manganese, and iron deposits traveled to Europe for treatment, although "the period of export of our crude minerals has been uniformly brief" (1929, p. 90). The model does not indicate how much time the cycle requires or what influences the amount of time. The model is perhaps more useful for explaining the colonial pattern of resource exploitation than the more recent period of increasing importance of developing country mineral producers and their political and economic independence. In spite of its shortcomings, the dynamic element of the model provides a valuable contribution.

Before turning from the topic of historical legacy, a reiteration of the comment made above in regard to capital is appropriate. Since capital costs are frequently lower for a brownfield expansion than for a greenfield facility, expansions at existing locations may be more advantageous than greenfield developments. Thus, the past location of minerals processing is important because of its ability to exert a continuing influence on the location of new capacity.

How relevant are these theories to explaining the patterns and trends we have identified for the processing of aluminum, copper, iron, nickel, tin, and zinc? It is to this question that we now turn.

## RESULTS

***Alumina.*** We have seen a growing percentage of alumina production by developing countries and by major bauxite producers. The evidence indicates that bauxite availability is becoming a more important criterion for the location of alumina production. However, bauxite represents only 30 percent of the value-added for alumina.[3] The availability of other inputs, particularly capital and energy, are also very important. The capital requirement is large due to the scale of

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[3] Calculation based on data in UNCTAD, 1982 using 1980 prices.

production. Banks (1979) estimates that the smallest possible plant for producing alumina should have a capacity of 300,000 tpy and that capital costs represent about 40 percent of total production costs. Transportation cost savings represent another incentive for processing near the mine. Conversion to alumina reduces the weight by approximately half, and the ease of handling and shipping of alumina is comparable to bauxite. Alcan built the first refinery in the Caribbean because its refineries in Canada were at a greater distance from the mines and thus at a disadvantage, relative to U.S. producers. Over the period, a number of new producers have entered the market, frequently via joint ventures, thereby reducing the degree of vertical integration in the industry. Long-term contracts are common and help to provide supply security for the non-integrated firm. The International Bauxite Association reports that over 80 percent of internationally-traded bauxite and alumina involves inter-affiliate transfers or long term contracts (Rodrik, 1980).

Political influence in the alumina industry has taken many forms. Early refining capacity in the U.S. was encouraged for security reasons because during World War II shipments of bauxite were vulnerable to enemy attack.[4] The cold war mentality engendered the attitude that it was more desirable to ship the low-value bauxite than to risk losing the higher-value alumina (Girvan, 1976 and Davis, 1982). As a result, both Reynolds and Kaiser expanded their alumina production capacity in the U.S. in the 1950s despite evidence that it would have been more economical to build new plants next to their mines in the Caribbean (Girvan,

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[4] During 1942 and early 1943, 26 ships transporting bauxite were sunk out of a total 915 sailings between Surinam and the U.S.A. (Davis, 1982).

1976). Of more recent significance is the increase in the bauxite levy from $2.50 to $11.50 per ton, enacted by Jamaica in 1974, and adopted by a number of other producers. Auty's (1983) analysis for the late 1970s concludes that the bauxite levy rendered a greenfield refinery in Jamaica so high-cost that even without further taxation of profits such a plant would be 15 percent more expensive to operate than a greenfield unit in Western Australia.[5] Nationalization in the bauxite industry permitted developing country governments to exercise more control over the building of alumina facilities. The risk of nationalization and the increased uncertainty about taxation have undoubtedly influenced the investment decisions of the private aluminum companies; however, the magnitude of the impact remains unquantifiable and subject to speculation.

The aluminum industry has exhibited higher rates of growth than any other metal under consideration. This factor has contributed to the development of new alumina capacity and a shift toward more competitive locations. While bauxite availability is an important factor for alumina processing locations, the availability of capital and energy have also been shown to be influential. Political factors have played an important role, especially as they contribute to the perceived political risk of competing locations. From a position of virtual insignificance in 1960, Australia has risen to the world's largest alumina producer, producing over 20 percent of the world's output in 1980. Australia combines the

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[5] Jamaica seems to have recognized this result and announced the objective of restoring Jamaica as a "priority area in the aluminum companies'" investment plans, during negotiations for the extension of the agreement effective January 1984. See *Metal Bulletin*, December 30, 1983, p. 9.

attributes of bauxite availability, large domestic energy reserves, and a well-developed capital market, while maintaining a political system that appears to be acceptable to many multinational mining companies.

*Aluminum.* In contrast to alumina, aluminum exhibits a decline in the amount produced within developing countries or by major bauxite producers. In fact, the ratios for aluminum production are the lowest of the eight commodities under review. Clearly, bauxite availability is less influential than other factors and this is not surprising, given that bauxite represents only 6 percent of the value-added for aluminum (UNCTAD, 1982). Energy is a considerably larger portion of the value-added. Peck (1983) estimates energy costs at U.S. smelters in 1982 ranged from 3.2 to 26.8 cents per pound of aluminum, with a weighted average of 16.8 cents. Furthermore, he found that the cost of electric power is a critical determinant of the location decision because its price varies more by location than the costs of the other inputs. Hence, the energy cost savings at the most advantageous location more than compensates for the additional costs incurred by a less than optimal location for the other inputs. One reason for large energy cost differentials is that electric power can not be transmitted long distances economically. Energy availability, more so than economies of scale, is largely responsible for the ultimate size of a smelter (Peck, 1983). While the weight reduction in the conversion of alumina into aluminum is approximately half, the transport cost savings is less than that because aluminum ingots are more expensive to transport on a per ton basis than alumina. Some evidence exists that market access influenced the processing location. In the 1960s, the major North American producers began to invest in aluminum smelters in Western

Europe because demand there was growing rapidly. At the same time, European producers began to build smelters in the U.S. (World Bank, 1983). Peck (1983) distinguishes between two types of smelters built abroad by U.S. firms. The first were those designed to serve the U.S. market and these locations offered low-cost, hydroelectric power. The second type were built to serve regional markets; for this second type, energy costs appear to be a secondary consideration. Since the North American producers were able to develop smelters abroad and export aluminum into the U.S. market, it appears reasonable that European companies could have pursued the same option. Therefore, the desire of European companies to establish capacity within the U.S. rather than simply export to the U.S. would indicate that market proximity was considered important. The location of aluminum production in 1980 is more closely aligned with consumption than with the production of bauxite or alumina.

Due to its defense industry applications aluminum is a strategic mineral and thus subject to a large degree of political attention. For example, during World War II the U.S. government built nine smelters and sold them below cost to private firms after the war. The Canadian industry also received support during the war from various governmental sources. In 1950, the U.S. and Canada together accounted for more than two-thirds of world aluminum production. More recently, government subsidy has taken the form of low-cost energy. For example, from the mid-1950s to the mid-1970s electricity rates paid by aluminum smelters to the Bonneville Power Administration were about one-fifth of the rate available to other large consumers (World Bank, 1983). While an incentive certainly exists for aluminum smelters to locate near low-cost power, the presence of the low-cost energy may reflect either a true savings or a political decision to subsidize the industry. In the event of the latter, the buyer must be convinced that the long term commitment is a secure one before the large amount of capital will be committed. Thus the search for low-cost energy is influenced by political factors, and therefore by political risk. Another political factor is the use of tariffs. The EEC and Japan have *ad valorem* tariff rates on aluminum ingot of six and nine percent, respectively. While lower or zero rates are available to some developing countries under the generalized system of preferences, these tariffs can still present an obstacle to developing country efforts to export aluminum.

The impact of the historical legacy on the current location of aluminum processing is mitigated by the fact that, of all the metals under study, aluminum has had the shortest commercial existence and the highest growth rate. The high growth rate has led to significant expansions in capacity, permitting the industry to adopt more competitive locations. The application of the Hewett model is hindered slightly by the youthfulness of the industry: no country, with the possible exception of France, has yet progressed through the five cycles. Nevertheless, the evidence thus far suggests that only those bauxite producers that are also well-endowed with energy are likely to develop a smelting industry, thereby progressing to stage 3 of the model.

*Blister Copper.* In contrast to the aluminum industry, developing countries and major ore producers have historically accounted for a large proportion of blister copper production; however, over the last decade a downward trend has appeared. This indicates that mine production is a fairly important determinant of smelter location, although its importance may be diminishing. A further contrast with the aluminum industry is the high portion of value-added that accrues at the mining stage, estimated at over 75 percent based on 1977 values (Kirthisingha, 1982). The majority of the copper that is exported before smelting comes from the Pacific rim, including Canada, Australia, the Philippines, and Papua New Guinea. Much of this mine production is of a fairly recent vintage and located convenient to port facilities. For example, the Bougainville mine of Papua New Guinea opened in 1973 and ships concentrates to Japan and Europe under long term contracts. These contracts constitute part of the financial package that was required to develop the project. In the past much of the concentrate production of the Philippines has been smelted in Japan; however, the Philippines brought a smelter-refinery complex on stream in late-1983. Much of the concentrates previously exported to Japan will be processed domestically and Japan will import refined copper instead. The Philippines have found it necessary to offer a slight discount in order to attract buyers, presumably due to its relatively unknown reputation as a supplier.

Smelting of the majority of Canadian ores takes place domestically; however, a downward trend has developed since the late 1960s as mine output in British Columbia has grown. Output from the initial mines was too small to warrant building a smelter. The lack of a local market for the byproduct sulfuric acid further hindered the development of a local smelting industry. Transportation costs to smelters in Manitoba or eastern Canada proved to be high relative to ocean transport to smelters in Japan. Furthermore, Japanese smelters offered very competitive terms under long term contracts, such that when the mine output in British Columbia grew to a size sufficient to support a local smelting industry, the mining companies continued to find it advantageous to export concentrates to Japan rather than invest in smelting capacity (Wittur, 1974). In fact for much of the 1970s the "sellers" market that existed for concentrates discouraged most new investment in smelting capacity in Canada (Wittur 1974, Balogh, 1978).

Transportation costs have also influenced the smelting location for African and South American concentrates. Zaire and Zambia have always smelted their concentrates before exporting. The mines in both Zaire and Zambia are located far from ports and overland transportation facilities are limited. The economies of transporting bulk concentrates by rail, relative to metal ingot, are less substantial than in ocean shipping (Wittur, 1974). The saving in transport costs due to the weight reduction from smelting compensates for the fact that much of the materials for the smelting process must be brought into the remote areas. Mine production in Chile and Peru is invariably within access of port facilities. As a result it is economical to export concentrates, however, in 1980 both countries were smelting almost 90 percent of their concentrates.

The only countries that have major smelting industries without significant mine output are Japan and, on a much smaller scale, the Federal Republic of Germany. Japanese blister copper production ranks as the world's fourth largest. Reasons for Japan's position appear to be influenced by political objectives, and import restrictions on blister have subsidized domestic smelters by supporting a domestic price in excess of the world price (Balogh, 1978 and Whitney, 1976). In addition, both countries have markets for the byproduct sulfur.

Another concern of the political system, environmental quality, affects the copper industry most seriously at the smelting stage. This is due to the separation of the copper from sulfur and other impurities that takes place during smelting. Environmental regulations in many developed countries call for reduction of sulfur dioxide emissions, often necessitating a large capital investment. In 1980 and 1970 the U.S. smelted less concentrates than it produced, reversing the pattern exhibited in 1960 and 1950. Furthermore, a smaller absolute amount of copper was smelted in the U.S. in 1980 than in 1970. Could this situation be the result of environmental regulations? Whitney's (1976) analysis covering the period up to 1972 concluded that environmental problems were not a determinant of smelter locations; however, the impact of environmental problems and the attention they have received have multiplied since 1972. Environmental concern provides a possible interpretation of the Japanese contribution to the rise of the Philippine smelting industry. Japanese firms provided both technical expertise and financing assistance. Japan has also contracted to buy considerable amounts of the output, at the same time that the Japanese smelting industry is operating well below capacity. This pattern of behavior would be consistent with the goal of exporting polluting activities to protect the domestic environment.

The behavior of the copper smelting industry provides some support to the Hewett model. New mining areas, such as those in British Columbia, Australia, Papua New Guinea, and the Philippines, exhibit a pattern of export-orientation prior to developing a local processing industry. The period will be prolonged, as it was for mines in British Columbia, if opportunities to sell concentrate are more economically attractive than investment in new capacity.

In summary, most concentrates are smelted near the mine to economize on transportation costs. Where smelting occurs at long distances from the mines, primarily in Japan and the F.R.G., these smelters tend to be market-oriented and revenues from the byproduct sulfur help to offset the cost disadvantage incurred in transport. Import restrictions further aided the viability of the Japanese smelting industry.

*Refined Copper.* The location of copper refining has historically been somewhat more market-oriented than smelting, although the share processed by developing countries has increased over the period. The share of copper refined by the major ore producers has remained fairly steady. In addition to Japan and the F.R.G., who have smelting industries, Belgium and the United Kingdom constitute the countries with substantial refined copper production without substantial domestic mine production. Their comparative advantage appears to be their location near large industrial markets. The availability of copper scrap may also be advantageous, though this can not be considered a major determinant.

The weight reduction between smelting and refining is not large enough to generate transportation cost savings, nor does the transformation from blister to refined copper result in significant differences in handling or loading. Historically refineries have often been located at the point where the mode of shipment changes, to economize on handling costs, such as packaging and terminal charges (Whitney, 1976).

Economies of scale tend to be larger for refineries than for smelters, partly due to the economies of by-product recovery. Blister copper frequently contains significant amounts of gold, silver, or lesser byproducts. Refining separates these metals from the copper and some amount of additional processing is required for each byproduct to be in a marketable form. Economies of scale in the byproduct recovery circuits can influence the economically-efficient size of the overall refinery. The increasing complexity from multi-product recovery requires greater technical expertise and skilled labor. Since there are fewer refineries than smelters, a refinery frequently depends upon blister copper from more than one source (Whitney, 1976). Hence, locations within a well-developed transportation network are advantageous. The output of the refinery involves a variety of products, including the byproduct metals plus the copper in several shapes such as cathodes, wirebars, billets and alloys, that may require special handling and packaging. A savings in handling and packaging costs can arise if the refinery is near semi-fabricating plants. While each factor alone may appear inconsequential, the combined effect is a slight advantage to locating refineries near markets.

*Iron*. The downward trend in the amount of iron ore processed domestically, which was slightly less than 50 percent in 1980, is evidence of the declining pull exerted by the location of inputs. In the nineteenth century, when up to eight tons of coking coal were required to produce one ton of pig iron, the iron making industry located most efficiently in areas where iron ore and coking coal were found in close proximity (Manners, 1971). Industries dependent on iron and steel tended to locate close to the mills (Manners, 1971). Improved iron making techniques have reduced both the iron ore and coking coal requirements significantly, and in conjunction with transportation economies, have enabled the industry to become more market oriented. Changes in steel making technology have also led to a more important role for scrap, as both a substitute and a complement for pig iron. Therefore, proximity to consuming centers is advantageous for facilitating scrap collection.

Over the period of the study, significant reductions in transport costs for bulk commodities, which includes both iron ore and coal, have occurred. The 10-20,000 ton ore carriers of the 1950s have been displaced by carriers as large as 150,000 tons (Santos, 1976). In 1950 the cost per ton of ore for transportation from Brazil to Japan was about $20; by 1965 the rate was as low as $4 (current dollars) (Santos, 1976). While one example serves to document the magnitude of the cost reductions, it should be kept in mind that shipping rates vary considerably by specific route and length of journey, frequency, port charges, and a myriad of other factors. The net effect of transport costs on the processing location must also account for the transport of other inputs, such as coal, and the transport of the output. While stressing the complexity of the countervailing forces, Manners (1971) concludes that the net affect favors a market orientation. The result is due in part to the fact that the output is not a bulk commodity and its distribution involves a larger number of buyers. Most iron ore and coal exporters are dependent upon one or two major importers (UNCTAD, 1981A), while the trade in finished steel mill products is more diffused.

While economies of scale have become larger for conventional iron and steel making processes over the period, some new technologies have enabled efficient production at smaller scale. These new technologies include direct reduction for iron production, the electric arc furnace for steel production, and the continuous caster for semi-finished products. The conventional process for making steel begins with the production of pig iron in a blast furnace. The blast furnace requires a large amount of capital[6] and is efficient only for large-tonnage production. An alternative to the blast furnace is the direct reduction process, which results in a product called sponge iron, and is especially appropriate for locations where natural gas or other suitable fuels are abundant. About 85 percent of the sponge iron produced is converted to steel in captive or associated electric arc furnaces (World Bank, 1982). These technologies are especially appropriate for developing countries with small markets.

Countries that desire to produce iron in excess of their domestic requirements encounter serious problems due to the high degree of vertical integration in the iron and steel industry. This vertical integration results from economies in the use of heat and energy, the movement of scrap, and the ease of management (Manners, 1971). For example, pig iron is often transferred from the blast furnace to the steel furnace in molten form, because the conservation of heat from the first stage reduces the energy requirements of the next stage. The advantage of having the steel furnace in close proximity is obvious. In regard to the movement of scrap, an integrated operation permits the trimmings from

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[6] UNIDO, (1980) estimates that the capital cost for annual ton of steel capacity is $818 for blast furnace/basic oxygen facilities and $370 for direct reduction/electric furnace mini mills (1978 dollar values).

the mill and any poorly cast ingots, etc. to be easily circulated back into the steel furnace. Transporting this scrap within an integrated plant is often cheaper than transporting it between unintegrated plants. The third advantage of vertical integration is that control of the entire operation by a single management is likely to yield greater efficiency. This vertical integration is largely responsible for the lack of an international market for pig iron. Therefore a country that desires to process its iron ore before export must integrate forward into semi-fabricated steel products. The marketing of these products is significantly more difficult in comparison to either iron ore, because there are a larger number of smaller buyers for the semis, or nonferrous metals, such as copper or zinc, that can be easily traded on a metals exchange.

A further market-related problem that steel exporters encounter is the existence of tariffs and quotas designed to protect the domestic steel industry in many developed countries. The fact that international agreements now in effect are reducing tariffs in steps between 1980 and 1987, does not appear to be attenuating the use of quotas, especially during the recent period of overcapacity (U.S. Bureau of Mines, 1983). Trade restrictions reflect in part the willingness of developed country governments to subsidize inefficient production in an effort to avoid the social problems of relocation in the industry. Many countries have used their steel industry as a tool for achieving regional development objectives. This is as true for the developed countries as for the developing countries, and also explains some of the investments made by the Soviet Union (Manners, 1971). Based partly on the success of the developed countries' regional development policies, some developing countries, such as Venezuela, have chosen the steel industry as a springboard for resource-based industrialization. Pollution control in developed countries may work to encourage relocation towards the developing world where environmental regulations are not as strict. For the U.S. iron and steel industry the estimated investment in pollution control was $400 million per annum, over the 1972 to 1981 period, and the task is far from complete (U.S. Bureau of Mines, 1983).

During the recent period of over capacity, some industry specialists have begun to anticipate a permanent slowdown in the growth of demand for steel in the developed countries. Over the period 1970 to 1980 pig iron production in developed countries registered no growth, while the developing countries output increased from 18.3 to 43.3 million tons, an increase of over 200 percent. Although the developed and socialist countries will continue to dominate the world iron and steel industry for the foreseeable future based on their current capacities, growth in the developing countries' output may continue to exceed that in the developed countries as technology favors smaller scale operations and permits the developing world to service their domestic markets.

While an integrated steel industry may be beyond the reach of many developing countries, agglomeration provides an opportunity for ore exporting countries to share in a bit more of the value-added. Agglomeration of low grade ores is an intermediary stage between iron ore and pig iron, that is common in the developed countries. The process, which was first proven economical in the United States in the 1950s, has spread to the point where almost 100 percent of ore produced in the developed countries is agglomerated. The comparable figure for the developing countries, however, was only 22 percent in 1979, despite the fact that it can have a significant value-added impact.[7] Agglomeration is essential for ores with an iron content of less than 50 percent. The fact that ores from most developing countries are of a higher iron content helps to explain the low share of ores agglomerated by developing countries. Two agglomeration processes are commercial, sintering and pelletization. Sintering results in a product that deteriorates with travel. In addition, its production uses coke breeze, which is a byproduct of metallurgical coal: therefore, sintering usually takes place near the blast furnace. For example, Japan sinters the ore that it imports from Australia and Peru. Pelletization requires energy and manufacturing-like equipment and technology that the developing countries may find prohibitive.

In applying the Hewett model to the iron and steel industry, we see that many developed country steel industries have become dependent on iron ore imports due to a decline in local ore production. However, over the period of this study, the lack of domestic ore supplies has not constrained the development of steel industries in those developed countries without domestic ore production, such as Japan. Furthermore, some large iron ore producers have failed to develop, or have only recently begun to develop, processing industries commensurate with their iron ore production capability. The size of domestic markets has undoubtedly constrained the development of an iron and steel industry in these countries. The relatively recent development of technologies

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[7] UNCTAD data from 1969 to 1977 show that pellets were sold at an average price premium of 33 percent (in real terms) relative to lump ore of the same iron content from the same producer (1978).

permitting efficient operation at smaller scales has permitted some developing country ore producers to begin iron and steel production.

*Nickel.* All the major nickel ore producing countries have processing capability. Since 1950 a fairly consistent 60 percent of ores have been processed domestically. The role of developing countries in processing has increased significantly, due primarily to a shift in the relative importance of lateritic ores. There are two major types of nickel ores: sulfide ore and oxide or lateritic ore. Lateritic ores are found primarily in tropical climates; hence, production from developing countries tends to be from lateritic ores. Due to the fine dissemination of nickel in the ore, lateritic ores are not economical to concentrate in the manner of sulfide ores. Instead, lateritic ores are smelted without concentration and the end product is ferronickel, a product used directly by the steel industry. In fact, changes in steelmaking technology over the period have rendered ferronickel more acceptable to the steel industry relative to refined nickel. Transport cost savings encourage processing near the mine for both sulfide and lateritic ores; however, the infeasibility of concentrating lateritic ores makes the transport cost savings relatively greater. As a result of the rise in the share of nickel from lateritic ores, more processing is taking place near the lateritic mines, and therefore, more processing is taking place in developing countries. For Canada, the major producer of sulfide ores, the combined availability of ore production and the other factor inputs, in particular hydroelectric power, and a domestic steel industry explain its prominent role in processing.

The major factors responsible for the 35 to 40 percent of the ore not processed domestically are government policy and the historical legacy. In 1970 and 1980 Japan was the world's third largest refined nickel producer, accounting for 15 percent of world production, in spite of the lack of domestic resources. Japan committed itself to the development of a local processing industry and achieved its objective by securing supplies of the raw material and enacting tariffs to protect the industry from lower-cost, foreign competition (Hubbard, 1975). In 1965 Inco's desire to break into the Japanese market resulted in its becoming a partner in a joint venture with two Japanese companies. The new refining company, the Tokyo Nickel Company, relies upon raw materials supplied by Inco. Historical legacy helps to explain the relative position of Norway and the United Kingdom. In 1928, the International Nickel Company (INCO) acquired the Mond Nickel Company of Great Britain, thereby acquiring a nickel refinery in Wales that is still in operation. When incorporated in Canada in 1928, Falconbridge already owned a refinery in Norway and has over the years expanded and modernized the refinery to keep pace with its Canadian mining and smelting operations. These refineries exemplify the ability of the processing industry to remain viable long after the local mines have been exhausted. While the relative importance of Norway and the United Kingdom has clearly declined over the period, their continued importance testifies to the tenacity of the historical legacy in the processing industry.

*Tin.* Over the period of the study, developing countries have progressed from smelting less than half of their tin ores in 1950 to over 90 percent today. Malaysia, the largest producer over the entire period, smelts all its domestic concentrates in addition to a substantial, though declining, amount of imports. The early Malaysian smelting industry was built with British capital. The necessary technology for smelting the type of ore found in Southeast Asia is not too complex and appears to have been readily available commercially. The availability of technology partly reflects the lack of vertical integration in the industry. The availability of other inputs varies by country. Thoburn (1981) concludes that in 1970 only 25 percent of the Malaysian mining industry's purchases of intermediate products were imported, while the comparable figure for Bolivia was 85 percent. Hence, smelting in Bolivia is less economically attractive and in 1980 only half its concentrates were processed domestically. A further difficulty for the Bolivian industry is a harder, more complex ore that produces a concentrate of lower tin content, more difficult to smelt than the typical ore from southeast Asia.

Over the 1950 to 1980 period a steady contraction of the developed country tin processing industry has taken place. Smelters in developed countries relied primarily on imported concentrates, the supply of which has dried up as developing countries have provided for more domestic processing. Thoburn (1981) cites the developing countries' desire to improve their bargaining position relative to purchasers as a major motivation for the shift in processing location. The marketing of refined tin was not an obstacle due to the lack of vertical integration and the arm's-length markets provided in Penang, New York, and by the London Metal Exchange. Smelting, which represents less than 5 percent of the gross output value for the tin produced in Southeast Asia, appears to have been a financially attractive investment (Thoburn, 1981).

Furthermore, domestic smelting results in transport cost savings due to a weight reduction of approximately one-third.

Governments have played an active part in furthering local processing. At the turn of the century, Malaysia enacted a duty on the export of unsmelted tin. The establishment of Thailand's smelter in 1965 by Billiton was supported by Thailand's Board of Investment with a prohibition on exports of unsmelted ore and a 5-year ban on the establishment of any additional smelting capacity (Thoburn, 1981). The U.S. smelting industry was built to treat imported ores for the strategic stockpile, as well as for current consumption (Robertson, 1982). In the 1950s, both Bolivia and Indonesia nationalized the major firms in their tin industries. Before nationalization very little smelting took place domestically. Since nationalization both countries have integrated forward into smelting, with Bolivia smelting 50 percent and Indonesia 100 percent of their mine production in 1980. The control over the industry that resulted from nationalization undoubtedly aided Bolivia and Indonesia in meeting their objective of increased local processing.

In summary, local processing has proven to be economical. The relatively rapid shift in processing in favor of developing, producing countries, especially in light of the low rate of growth in the industry, is due in large part to government policy in the developing countries. Access to the technology, availability of markets, and the lack of vertical integration facilitated the progress of the developing countries.

*Zinc.* Sixty percent of the zinc mined is smelted domestically and this portion has remained fairly constant over the last thirty years, indicating that a domestic supply of concentrates is advantageous but not an essential criterion for a smelting industry. The U.S. decline in smelter output has been partially attributed to the decline in domestic mine production; however, the ability of the Japanese and European industries to expand output during the same time period despite their dependence on imported concentrates, indicates that other factors have contributed to the decline of the U.S. industry. Economies of scale exhibit declining average costs up to a capacity of approximately 100,000 tpa (Wittur, 1974). Increasing economies of scale have resulted in higher capital requirements; however, the technology has been readily available (Hillman, 1977) and the existence of smelters in so many developing countries indicates that the availability of technology and capital has not been a serious constraint. Wittur (1974) does cite a period prior to 1970 when excess smelting capacity kept smelting charges low, hence toll smelting was financially more attractive for the Canadian zinc mining industry than investment in local smelting capacity. In 1970 Canada was smelting only one-third of domestic zinc concentrates. Transportation costs played a fairly neutral role in the Canadian processing location. Rail rates to existing smelters were high relative to ocean shipping rates; while ocean shipping rates were cheaper per ton for concentrates than for metal, the savings was completely offset by the weight reduction resulting from smelting (Wittur, 1974). So, advantageous smelting terms from abroad had a greater influence on the decision to export concentrates than did transport economies. Smelters close to industrial centers have the advantage of being able to market the byproduct sulfur. Thus smelters in Japan and Europe have been able to offer lower smelting charges.

The history of government assistance or intervention in the zinc industry is long and colorful.[8] Memories of tight supplies during World War II led the U.S. government to provide assistance to both foreign and domestic producers when the Korean conflict began. The government programs provided exploration funds, development loans, and long term purchase contracts with floor prices. Foreign countries receiving aid under these programs included Peru, Yugoslavia, Spain, and Mexico. At the same time, the supply problems experienced by Switzerland led to a loan of 150 million Swiss francs to Belgium for the construction of a 40,000 tpa electrolytic zinc smelter in the Belgian Congo (now Zaire). The U.S. government was perhaps too successful in encouraging new capacity and by 1958 the glut in the market resulted in the U.S. adopting quotas to protect the domestic industry. This action may have actually encouraged foreign producers to build smelters to process the concentrates that had previously been exported to the U.S. Quotas were abolished in 1965. Japan and the EEC maintain tariffs on zinc metal but not on concentrates, so as to benefit their domestic smelting industries. The U.S. maintains tariffs on both concentrates and metal. While tariffs have aided the mining industry, they have hindered the smelting industry. The tariff structure of Japan and the EEC encourages countries to export concentrates to those markets; however, the tariff structure of the U.S. is fairly neutral between concentrates and refined metal. The result is that the overwhelming majority of zinc imported by the U.S. is in the form of slab zinc rather than concentrates. From 1969 to 1972 approxi-

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[8] For a more complete analysis, the interested reader is referred to Hillman (1977) from which this brief summary is taken.

mately 30 percent of the U.S. zinc smelting industry was shut down. The U.S. went from the largest zinc producer in 1970 to fourth largest in 1980. Closure of the U.S. smelters has been linked to the potentially onerous impact of environmental regulations; however, Hillman (1977) attributes the closures to the inability of the U.S. producers to justify new investment, particularly in light of the age of the facilities and, perhaps more importantly, due to the adverse government policies of tariffs and price controls. The Japanese industry was able to double its smelting capacity between 1965 and 1970 due in part to the large subsidies it received in the forms of tariff barriers, tax relief, low interest loans and direct cash grants (Hillman, 1977). In Canada, the Ontario government pressured Texasgulf into building a new smelter in the late 1960s to treat ores from its Kidd Creek mine, by providing an $8 million subsidy (Hillman, 1977).

Application of the Hewett model to the zinc industry provides conflicting results. Wittur (1974) in his analysis of the Canadian industry provides evidence of the lag between the development of mine capacity and that of smelting capacity. The data for the U.S., on the other hand, does not support the Hewett model. As domestic mine production has declined, the smelting industry has declined even more dramatically. Instead of a viable smelting industry surviving the closure of domestic mines by relying upon imports, an equilibrium between mine output and smelter production has developed. The behavior pattern conflicts with the expectation of a viable smelting industry surviving the depletion of domestic reserves. In this case, government policy and the age of the smelters were the determining factors.

## CONCLUSIONS

This chapter illustrates the simple fact that comparative advantage at one stage of processing does not guarantee comparative advantage at subsequent stages. The inputs required for each production process, as well as the impact of public policy and the historical legacy vary at different stages. Furthermore, the determining factors differ by commodity. The perception that too little mineral processing takes place in developing countries can not be explained simply by allegations of discrimination on the part of the developed countries or by arguments of the inherent political riskiness of some developing countries. This is not to say that discrimination or political risk are irrelevant, only that the underlying factors are more complex. A satisfactory explanation for the role of developing countries in minerals processing must also contribute to our understanding of the role of developed country mineral producers, who do not process 100 percent of their mineral output either. Furthermore the fact that the share of developing countries' exports represented by complex, finished goods has increased over this period, indicates that specialization at early stages of some processing chains can not be explained by the inability of developing countries to produce more elaborate products (UNIDO, 1981). Rather, explanations of barriers to domestic processing are the result of characteristics specific to each commodity and each processing activity.

For the commodities of interest to this study, determinants of the location of processing involve several economic and political factors that interact with the historical legacy. For alumina processing, government policies among bauxite producing countries have been of primary importance; transport cost savings and capital availability were influential, though of relatively less importance. In aluminum production, the availability of low cost energy is an overriding concern, although, it should be noted that public policy has frequently supplanted the market in the pricing of energy. Transport cost savings and the market for byproduct sulfur are the primary determinants of the location of copper smelters. Copper refineries, on the other hand are more market oriented, and tend to be located at transshipment points. For iron ore, proximity to the source of inputs has become less important due to transportation economies for bulk commodities as well as a reduction in the required inputs per ton of output. Technologies permitting efficient operation on a smaller scale have also contributed to a market orientation and have encouraged more iron and steel production in developing countries. In the nickel industry, the interaction of the technology for treating lateritic ores and the transport cost savings has been as important as tariff structures and historical legacy. The shift toward local processing in the tin industry is largely attributable to government policy whose success was aided by the structure of the industry. In the zinc industry, tariffs and other political interventions have helped to shape the pattern of smelter locations.

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## Appendix Table 1

## Alumina Production by Country and Country Group, Selected Years, 1950-1980[a]

| Country and country group | 1955[b] | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total |
| Developed Countries | 2542 | 80 | 3142 | 69 | 6544 | 62 | 11097 | 63 |
| Australia | 0 | 0 | 15 | --[c] | 1076 | 10 | 3624 | 21 |
| U.S. | 1473 | 46 | 1757 | 38 | 3026 | 28 | 3505 | 20 |
| Japan | 69 | 2 | 177 | 4 | 643 | 6 | 1109 | 6 |
| F.R.G. | 190 | 6 | 218 | 5 | 379 | 4 | 804 | 5 |
| France | 174 | 5 | 297 | 7 | 502 | 5 | 670 | 4 |
| Canada | 500 | 16 | 500 | 11 | 553 | 5 | 601 | 3 |
| Greece | 0 | 0 | 0 | 0 | 156 | 1 | 253 | 1 |
| Other | 136 | 4 | 177 | 4 | 210 | 2 | 532 | 3 |
| Developing Countries | 130 | 4 | 497 | 11 | 2187 | 20 | 3665 | 21 |
| Jamaica | 93 | 3 | 338 | 7 | 899 | 8 | 1198 | 7 |
| Surinam | 0 | 0 | 0 | 0 | 518 | 5 | 720 | 4 |
| Yugoslavia | 21 | 1 | 35 | 1 | 63 | 1 | 628 | 4 |
| Guinea | 0 | 0 | 86 | 2 | 305 | 3 | 354 | 2 |
| India | 7 | -- | 12 | -- | 164 | 2 | 256 | 1 |
| Brazil | 2 | -- | 18 | -- | 59 | 1 | 253 | 1 |
| Guyana | 0 | 0 | 0 | 0 | 159 | 1 | 148 | 1 |
| Other | 7 | -- | 8 | -- | 21 | 0 | 109 | 1 |
| Socialist Countries | 516 | 16 | 927 | 20 | 1908 | 18 | 2765 | 16 |
| U.S.S.R. | 400 | 13 | 700 | 15 | 1350 | 13 | 1625 | 9 |
| Hungary | 76 | 2 | 110 | 2 | 221 | 2 | 417 | 2 |
| China | 0 | 0 | 70 | 2 | 175 | 2 | 400 | 2 |
| Romania | 0 | 0 | 0 | 0 | 100 | 1 | 255 | 1 |
| Other | 40 | 1 | 47 | 1 | 62 | 1 | 69 | -- |
| TOTAL | 3188 | 100 | 4566 | 100 | 10639 | 100 | 17527 | 100 |

Appendix Table 1 continued

*Notes:*

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

[b] Data from 1955 are the earliest available.

[c] – indicates less than half a unit.

*Sources:* United Nations Conference on Trade and Development, *The World Market for Bauxite: Characteristics and Trends, Statistical Annex* (1982).

## Appendix Table 2

### Aluminum Production by Country and Country Group, Selected Years, 1950-1980[a]

| Country and country group | 1950 |  | 1960 |  | 1970 |  | 1980 |  |
|---|---|---|---|---|---|---|---|---|
|  | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total |
| Developed Countries | 1281 | 85 | 3499 | 77 | 7471 | 73 | 10964 | 68 |
| U .S. | 652 | 43 | 1828 | 40 | 3607 | 35 | 4654 | 29 |
| Japan | 25 | 2 | 133 | 3 | 728 | 7 | 1092 | 7 |
| Canada | 360 | 24 | 691 | 15 | 963 | 9 | 1075 | 7 |
| F.R.G. | 28 | 2 | 169 | 4 | 309 | 3 | 731 | 5 |
| Norway | 45 | 3 | 165 | 4 | 522 | 5 | 662 | 4 |
| France | 61 | 4 | 235 | 5 | 381 | 4 | 432 | 3 |
| Spain | 2 | --[b] | 29 | 1 | 120 | 1 | 387 | 2 |
| U.K. | 30 | 2 | 29 | 1 | 40 | -- | 374 | 2 |
| Australia | 0 | 0 | 12 | -- | 206 | 2 | 304 | 2 |
| Italy | 37 | 2 | 84 | 2 | 147 | 1 | 271 | 2 |
| Netherlands | 0 | 0 | 0 | 0 | 75 | 1 | 258 | 2 |
| Austria | 18 | 1 | 68 | 1 | 90 | 1 | 94 | 1 |
| Switzerland | 19 | 1 | 39 | 1 | 91 | 1 | 86 | 1 |
| Other | 4 | -- | 17 | -- | 192 | 2 | 544 | 3 |
| Developing Countries | 7 | -- | 114 | 3 | 585 | 6 | 1796 | 11 |
| Venezuela | 0 | 0 | 0 | 0 | 22 | -- | 317 | 2 |
| Brazil | 0 | 0 | 18 | -- | 56 | 1 | 261 | 2 |
| Ghana | 0 | 0 | 0 | 0 | 113 | 1 | 188 | 1 |
| India | 4 | -- | 18 | -- | 161 | 2 | 185 | 1 |
| Yugoslavia | 2 | -- | 25 | 1 | 48 | -- | 161 | 1 |
| Other | 1 | -- | 53 | 1 | 185 | 2 | 684 | 4 |
| Socialist Countries | 219 | 15 | 936 | 21 | 2246 | 22 | 3286 | 20 |
| U.S.S.R. | 209 | 14 | 700 | 15 | 1700 | 17 | 2420 | 15 |
| China | 0 | 0 | 70 | 2 | 180 | 2 | 350 | 2 |
| Romania | 0 | 0 | 10 | -- | 101 | 1 | 241 | 2 |
| Hungary | 7 | -- | 50 | 1 | 66 | 1 | 74 | -- |
| Other | 3 | -- | 106 | 2 | 199 | 2 | 201 | 1 |
| TOTAL | 1507 | 100 | 4548 | 100 | 10302 | 100 | 16045 | 100 |

Appendix Table 2 continued

*Notes:*

[a]Figures may not sum to totals due to rounding.
[b]-- indicates less than half a unit.

*Source: Metal Statistics* (various years).

## Appendix Table 3

### Copper Smelter Production by Country and Country Group, Selected Years, 1950-1980[a]

| | 1950 | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| Country and country group | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total |
| Developed Countries | 1344 | 53 | 1961 | 46 | 2956 | 47 | 3116 | 41 |
| U.S. | 915 | 36 | 1119 | 26 | 1489 | 24 | 1008 | 13 |
| Japan | 37 | 1 | 188 | 4 | 501 | 8 | 890 | 12 |
| Canada | 210 | 8 | 361 | 8 | 450 | 7 | 470 | 6 |
| South Africa | 33 | 1 | 48 | 1 | 148 | 2 | 186 | 2 |
| Australia | 16 | 1 | 72 | 2 | 112 | 2 | 171 | 2 |
| F.R.G. | 49 | 2 | 62 | 1 | 84 | 1 | 154 | 2 |
| Spain | 7 | --[b] | 13 | -- | 55 | 1 | 103 | 1 |
| Other | 77 | 3 | 98 | 2 | 117 | 2 | 134 | 2 |
| Developing Countries | 938 | 37 | 1689 | 39 | 2147 | 34 | 2688 | 35 |
| Chile | 346 | 14 | 505 | 12 | 647 | 10 | 953 | 13 |
| Zambia | 281 | 11 | 576 | 13 | 683 | 11 | 609 | 8 |
| Zaire | 172 | 7 | 302 | 7 | 386 | 6 | 426 | 6 |
| Peru | 23 | 1 | 164 | 4 | 177 | 3 | 326 | 4 |
| Yugoslavia | 40 | 2 | 36 | 1 | 87 | 1 | 94 | 1 |
| Mexico | 56 | 2 | 52 | 1 | 60 | 1 | 88 | 1 |
| Other | 20 | 1 | 54 | 1 | 107 | 2 | 192 | 3 |
| Socialist Countries | 240 | 10 | 633 | 15 | 1218 | 19 | 1770 | 23 |
| U.S.S.R. | 218 | 9 | 500 | 12 | 925 | 15 | 1150 | 15 |
| Poland | -- | -- | 17 | -- | 69 | 1 | 320 | 4 |
| China | NA[c] | NA | NA | NA | 100 | 2 | 150 | 2 |
| Other | 22 | 1 | 115 | 3 | 124 | 2 | 150 | 2 |
| TOTAL | 2522 | 100 | 4282 | 100 | 6320 | 100 | 7575 | 100 |

Appendix Table 3 continued

*Notes:*

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

[b] -- indicates less than half a unit.

[c] NA indicates not available. Data for China for 1950 and 1960 are included with Other Socialist Countries.

*Source: Metal Statistics* (various years).

## Appendix Table 4

## Refined Copper Production by Country and Country Group, Selected Years, 1950-1980[a]

| | 1950 | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| Country and country group | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total |
| Developed Countries | 2320 | 73 | 3303 | 66 | 4669 | 61 | 4871 | 52 |
| U .S. | 1344 | 42 | 1643 | 33 | 2035 | 27 | 1686 | 18 |
| Japan | 85 | 3 | 248 | 5 | 705 | 9 | 1014 | 11 |
| Canada | 216 | 7 | 378 | 8 | 493 | 6 | 505 | 5 |
| Belgium[b] | 137 | 4 | 195 | 4 | 338 | 4 | 418 | 4 |
| F.R.G. | 198 | 6 | 309 | 6 | 406 | 5 | 374 | 4 |
| Australia | 28 | 1 | 84 | 2 | 146 | 2 | 182 | 2 |
| U.K. | 193 | 6 | 219 | 4 | 206 | 3 | 161 | 2 |
| Spain | 14 | --[c] | 42 | 1 | 80 | 1 | 154 | 2 |
| South Africa | 13 | -- | 12 | -- | 75 | 1 | 148 | 2 |
| Other | 92 | 3 | 173 | 3 | 185 | 2 | 229 | 2 |
| Developing Countries | 540 | 17 | 896 | 18 | 1503 | 20 | 2216 | 24 |
| Chile | 300 | 9 | 226 | 5 | 465 | 6 | 811 | 9 |
| Zambia | 79 | 2 | 403 | 8 | 581 | 8 | 607 | 6 |
| Peru | 21 | 1 | 30 | 1 | 36 | – | 231 | 2 |
| Zaire | 97 | 3 | 145 | 3 | 190 | 3 | 150 | 2 |
| Yugoslavia | 18 | 1 | 36 | 1 | 89 | 1 | 131 | 1 |
| Mexico | 16 | 1 | 28 | 1 | 54 | 1 | 102 | 1 |
| Other | 9 | -- | 28 | 1 | 88 | 1 | 184 | 2 |
| Socialist Countries | 327 | 10 | 800 | 16 | 1419 | 19 | 2322 | 25 |
| U.S.S.R. | 280 | 9 | 610 | 12 | 1075 | 14 | 1450 | 15 |
| Poland | 12 | -- | 22 | -- | 72 | 1 | 357 | 4 |
| China | NA[d] | NA | NA | NA | 120 | 2 | 270 | 3 |
| Other | 35 | 1 | 168 | 3 | 152 | 2 | 245 | 3 |
| TOTAL | 3187 | 100 | 4999 | 100 | 7592 | 100 | 9409 | 100 |

Appendix Table 4 continued

*Notes:*

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

[b] Refined copper production of Luxembourg is included with the Belgian data for 1970 and 1980.

[c] – indicates less than half a unit.

[d] NA indicates not available. Data for China for 1950 and 1960 are included with Other Socialist Countries.

*Source: Metal Statistics* (various years).

## Appendix Table 5

### Pig Iron Production by Country and Country Group, Selected Years, 1950-1980[a]

| | 1950[b] | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| Country and country group | Millions of tons of contained metal | Percent of total | Millions of tons of contained metal | Percent of total | Millions of tons of contained metal | Percent of total | Millions of tons of contained metal | Percent of total |
| Developed Countries | 105.5 | 79 | 157.8 | 65 | 279.5 | 66 | 279.2 | 55 |
| Japan | 2.3 | 2 | 11.9 | 5 | 68.0 | 16 | 87.0 | 17 |
| U.S. | 60.2 | 45 | 60.3 | 25 | 82.8 | 19 | 62.4 | 12 |
| F.R.G. | 11.2 | 8 | 25.7 | 11 | 33.6 | 8 | 33.9 | 7 |
| France | 7.8 | 6 | 14.0 | 6 | 19.1 | 4 | 19.2 | 4 |
| Canada | 2.3 | 2 | 3.9 | 2 | 8.2 | 2 | 10.9 | 2 |
| Belgium | 3.7 | 3 | 6.5 | 3 | 11.0 | 3 | 9.8 | 2 |
| South Africa | 0.7 | 1 | 2.0 | 1 | 3.9 | 1 | 7.1 | 1 |
| Australia | 1.1 | 1 | 2.9 | 1 | 6.2 | 1 | 7.0 | 1 |
| U.K. | 9.8 | 7 | 16.0 | 7 | 17.7 | 4 | 6.4 | 1 |
| Spain | 0.7 | 1 | 1.9 | 1 | 4.2 | 1 | 6.4 | 1 |
| Luxembourg | 2.5 | 2 | 3.7 | 2 | 4.8 | 1 | 3.6 | 1 |
| Other | 3.2 | 2 | 9.0 | 4 | 20.0 | 5 | 25.5 | 5 |
| Developing Countries | 3.2 | 3 | 8.9 | 4 | 18.3 | 4 | 43.3 | 9 |
| Brazil | 0.7 | 1 | 1.8 | 1 | 4.2 | 1 | 13.0 | 3 |
| India | 1.7 | 1 | 4.2 | 2 | 7.0 | 2 | 8.5 | 2 |
| Mexico | 0.4 | --[c] | 0.7 | – | 1.6 | -- | 5.2 | 1 |
| Other | 0.4 | -- | 2.2 | 1 | 5.5 | 1 | 16.6 | 3 |
| Socialist Countries | 24.9 | 19 | 74.9 | 31 | 128.6 | 30 | 182.7 | 36 |
| U.S.S.R. | 19.2 | 14 | 46.8 | 19 | 85.9 | 20 | 109.0 | 22 |
| China | 1.0 | 1 | 13.5 | 6 | 16.2 | 4 | 35.4 | 7 |
| Poland | 1.5 | 1 | 4.6 | 2 | 7.3 | 2 | 10.0 | 2 |
| Romania | 0.3 | -- | 1.0 | – | 4.2 | 1 | 9.1 | 2 |
| Other | 2.9 | 2 | 9.0 | 4 | 15.0 | 4 | 19.2 | 4 |
| TOTAL | 133.7 | 100 | 241.5 | 100 | 426.5 | 100 | 505.3 | 100 |

Appendix Table 5 continued

*Notes:*

[a] Figures may not sum to totals due to rounding.
[b] Data for 1950 include ferroalloys.
[c] -- indicates less than half a unit.

*Source:* Manners (1971); United Nations Conference on Trade and Development, *Proposed Establishment of an Annual Statistical Programme Relating to Iron Ore: Statistics on Iron Ore* (1981).

## Appendix Table 6

## Refined Nickel Production by Country and Country Group, Selected Years, 1950-1980[a]

| Country and country group | 1950 | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total |
| Developed Countries | 118 | 80 | 254 | 78 | 402 | 69 | 447 | 60 |
| Canada | 64 | 43 | 122 | 37 | 189 | 32 | 152 | 20 |
| Japan | 0 | 0 | 19 | 6 | 90 | 15 | 109 | 15 |
| U.S. | 19 | 13 | 34 | 10 | 14 | 2 | 39 | 5 |
| Norway | 10 | 7 | 30 | 9 | 39 | 7 | 37 | 5 |
| Australia | 0 | 0 | 0 | 0 | 1 | --[b] | 35 | 5 |
| U.K. | 21 | 14 | 34 | 10 | 37 | 6 | 19 | 3 |
| South Africa | 0 | 0 | 1 | -- | 9 | 2 | 18 | 2 |
| Greece | 0 | 0 | 0 | 0 | 9 | 2 | 14 | 2 |
| Finland | 0 | 0 | 1 | -- | 4 | 1 | 13 | 2 |
| France | 3 | 2 | 10 | 3 | 11 | 2 | 10 | 1 |
| Other | 1 | 1 | 3 | 1 | 0 | 0 | 0 | 0 |
| Developing Countries | -- | -- | 11 | 3 | 53 | 9 | 114 | 15 |
| New Caledonia | -- | -- | 11 | 3 | 27 | 5 | 33 | 4 |
| Philippines | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 3 |
| Cuba | 0 | 0 | 0 | 0 | 18 | 3 | 20 | 3 |
| Dominican Rep. | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 2 |
| Zimbabwe | 0 | 0 | 0 | 0 | 5 | 1 | 15 | 2 |
| Other | 0 | 0 | 0 | 0 | 3 | 1 | 7 | 1 |
| Socialist Countries | 30 | 20 | 62 | 19 | 130 | 22 | 187 | 25 |
| U.S.S.R. | 29 | 20 | 58 | 18 | 124 | 21 | 165 | 22 |
| China | NA[c] | NA | NA | NA | NA | NA | 11 | 1 |
| Other | 1 | 1 | 4 | 1 | 6 | 1 | 11 | 1 |
| TOTAL | 148 | 100 | 327 | 100 | 584 | 100 | 748 | 100 |

Appendix Table 6 continued

*Notes:*

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

[b] -- indicates less than half a unit.

[c] NA indicates not available. Data for China for 1950, 1960, and 1970 are included with Other Socialist Countries.

*Source: Metal Statistics* (various issues).

## Appendix Table 7

## Tin Smelter Production by Country and Country Group, Selected Years, 1950-1980[a]

| | 1950 | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total | Thousands of tons of contained metal | Percent of total |
| ed | | | | | | | | |
| es | 99.0 | 53 | 69.5 | 34 | 50.7 | 23 | 26.2 | 11 |
| | 29.0 | 15 | 28.1 | 14 | 22.0 | 10 | 5.9 | 3 |
| lia | 2.0 | 1 | 2.3 | 1 | 5.2 | 2 | 4.8 | 2 |
| | 33.6 | 18 | 14.3 | 7 | 4.5 | 2 | 3.9 | 2 |
| | 1.5 | 1 | 0.7 | --[c] | 3.9 | 2 | 3.1 | 1 |
| m[b] | 9.7 | 5 | 8.1 | 4 | 4.3 | 2 | 2.8 | 1 |
| rlands | 21.4 | 11 | 11.8 | 6 | 6.3 | 3 | 1.1 | -- |
| | 1.8 | 1 | 4.2 | 2 | 4.5 | 2 | 4.6 | 2 |
| ing | | | | | | | | |
| es | 75.7 | 40 | 86.0 | 42 | 133.6 | 61 | 170.5 | 74 |
| sia | 69.9 | 37 | 77.4 | 37 | 90.3 | 42 | 71.3 | 31 |
| nd | 0 | 0 | 0 | 0 | 22.0 | 10 | 34.8 | 15 |
| esia | 0.4 | -- | 2.0 | 1 | 5.2 | 2 | 30.5 | 13 |
| a | 0 | 0 | 1.1 | 1 | 0.7 | -- | 14.4 | 6 |
| | 0.1 | -- | 1.3 | 1 | 3.3 | 2 | 8.8 | 4 |
| pore | 0 | 0 | 0 | 0 | 0 | 0 | 4.0 | 2 |
| ia | NA[d] | NA | 0 | 0 | 8.1 | 4 | 2.7 | 1 |
| | 3.3 | 2 | 2.5 | 1 | 1.4 | 1 | 0.8 | -- |
| | 2.0 | 1 | 1.7 | 1 | 2.6 | 1 | 3.2 | 1 |
| t | | | | | | | | |
| ies | 12.4 | 7 | 51.2 | 25 | 33.1 | 15 | 33.9 | 15 |
| .R. | 8.0 | 4 | 20.0 | 10 | 10.0 | 5 | 17.0 | 7 |
| | 4.1 | 2 | 30.0 | 15 | 22.0 | 10 | 15.0 | 7 |
| | 0.3 | -- | 1.2 | 1 | 1.1 | 1 | 1.9 | 1 |
| | 187.1 | 100 | 206.7 | 100 | 217.4 | 100 | 230.6 | 100 |

Appendix Table 7 continued

*Notes:*

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

[b] Production of Luxembourg is included with the Belgian data for 1970 and 1980.

[c] -- indicates less than half a unit.

[d] NA indicates not available. Data for Nigeria for 1950 are included with Other Developing Countries.

*Source: Metal Statistics* (various issues).

## Appendix Table 8

### Zinc Smelter Production by Country and Country Group, Selected Years, 1950-1980[a]

| | 1950 | | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|---|---|
| Country and country group | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total | Thousands of tons of contained metal | Per-cent of total |
| Developed Countries | 1717 | 83 | 2213 | 70 | 3562 | 68 | 3809 | 62 |
| Japan | 49 | 2 | 181 | 6 | 681 | 13 | 735 | 12 |
| Canada | 185 | 9 | 237 | 8 | 418 | 8 | 592 | 10 |
| U.S. | 826 | 40 | 787 | 25 | 866 | 17 | 370 | 6 |
| F.R.G. | 136 | 7 | 192 | 6 | 301 | 6 | 365 | 6 |
| Australia | 84 | 4 | 120 | 4 | 256 | 5 | 301 | 5 |
| France | 68 | 3 | 149 | 5 | 224 | 4 | 253 | 4 |
| Belgium[b] | 174 | 8 | 248 | 8 | 232 | 4 | 248 | 4 |
| Italy | 38 | 2 | 85 | 3 | 142 | 3 | 207 | 3 |
| Netherlands | 21 | 1 | 36 | 1 | 46 | 1 | 170 | 3 |
| Spain | 21 | 1 | 45 | 1 | 88 | 2 | 152 | 2 |
| Finland | 0 | 0 | 0 | 0 | 56 | 1 | 147 | 2 |
| U.K. | 71 | 3 | 76 | 2 | 147 | 3 | 87 | 1 |
| South Africa | 0 | 0 | 0 | 0 | 27 | 1 | 81 | 1 |
| Norway | 43 | 2 | 45 | 1 | 62 | 1 | 79 | 1 |
| Others | 1 | –[c] | 12 | – | 16 | -- | 22 | – |
| Developing Countries | 93 | 5 | 221 | 7 | 393 | 8 | 648 | 11 |
| Mexico | 49 | 2 | 53 | 2 | 85 | 2 | 144 | 2 |
| Yugoslavia | 12 | 1 | 36 | 1 | 59 | 1 | 85 | 1 |
| Brazil | NA[d] | NA | 0 | 0 | 9 | -- | 78 | 1 |
| Korea, Rep.of | 0 | 0 | 0 | 0 | 2 | -- | 76 | 1 |
| Peru | 1 | – | 32 | 1 | 69 | 1 | 64 | 1 |
| Zaire | 0 | 0 | 53 | 2 | 64 | 1 | 44 | 1 |
| Zambia | 23 | 1 | 30 | 1 | 54 | 1 | 33 | 1 |
| Other | 8 | – | 17 | 1 | 51 | 1 | 124 | 2 |
| Socialist Countries | 250 | 12 | 718 | 23 | 1263 | 24 | 1700 | 28 |
| U.S.S.R. | 129 | 6 | 400 | 13 | 725 | 14 | 1060 | 17 |
| Poland | 114 | 6 | 176 | 6 | 209 | 4 | 217 | 4 |
| China | – | – | 70 | 2 | 100 | 2 | 155 | 3 |
| Korea, D.P.R. | 0 | 0 | 45 | 1 | 90 | 2 | 105 | 2 |
| Bulgaria | 0 | 0 | 17 | 1 | 76 | 1 | 91 | 1 |
| Other | 7 | -- | 10 | -- | 63 | 1 | 72 | 1 |
| TOTAL | 2060 | 100 | 3152 | 100 | 5218 | 100 | 6157 | 100 |

Appendix Table 8 continued

*Notes:*

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

[b] Production of Luxembourg is included with the Belgian data for 1970 and 1980.

[c] -- indicates less than half a unit.

[d] NA indicates not available. Data for Brazil for 1950 are included with Other Developing Countries.

*Source: Metal Statistics* (various issues).