# INNOVATIVE ACTIVITY AND COMPARATIVE ADVANTAGE IN MINING

by

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**Abstract**

Economists have largely abandoned the factor endowment theory as an adequate explanation of international trade in manufacturing products and services, but still widely believe resource endowment is sufficient to explain comparative advantage in mining. Chile exports copper, Australia iron ore, and Canada nickel because these countries are blessed with high quality mineral deposits. Over time, as the high quality deposits are exhausted, comparative advantage should shift to countries with the next best deposits. The discovery of new, high quality deposits may also give rise to shifts in comparative advantage.

This view presumes that mining and mineral processing are relatively static in the sense that technological change and innovative activity more broadly have little influence on production costs and comparative advantage. The experience of the U.S. copper industry over the past several decades, however, suggests that this is not the case. Companies and even individual mines have through innovative activities managed to recapture their comparative advantage in copper mining. In this respect, international trade in mineral products may not be all that different from trade in manufactured products and other goods.

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## Introduction

Why some countries produce and export certain goods, while others import these goods and export a different set of goods has interested economists for centuries. Modern explanations found in the pure theory of international trade are based on the doctrine of comparative costs developed by David Ricardo nearly two hundred years ago. This doctrine contends that states will produce and export those commodities whose domestic production costs are low relative to other products when compared with production costs in other countries.

The doctrine of comparative costs is just the first step in accounting for comparative advantage. To be useful, it must be coupled with an explanation of why differences in comparative costs arise among countries. In the first attempt to answer this question, Ricardo and other classical economists pointed to differences in labor productivity. A farmer in the United States may produce many times the amount of food in a year as a farmer in India because of more favorable terrain, larger scale operations, and more mechanized farming techniques. Whereas an American worker assembling semiconductor devices may at best be only slightly more productive than his or her Indian counterpart. In the 20$^{th}$ century, neoclassical writers, such as Jacob Viner and Gottfried Haberler, have suggested focusing on differences in total productivity, rather than just labor productivity, to take into account the influence of factors of production other than labor.

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

Over the past several decades, numerous other explanations for differences in comparative costs have emerged. These theories stress the important of inter-country differences in the generation and diffusion of technology, in human capital, in opportunities to exploit economics of scale, in regional externalities, in domestic market conditions, in strategic trade policies to capture learning economics, and in the opportunities to realize economies of scope. These theories arose primarily to explain the large volume of trade between the industrialized countries in manufactured goods and services. While differences in factor endowments and productivity do exist among these countries, they typically are small compared with the differences between the developed and developing countries. Moreover, developed countries with similar domestic conditions, such as those of Western Europe, often import and export the same or similar final goods to each other.

This has produced considerable uneasiness over the validity and usefulness of the neoclassical and factor endowment theories in explaining trade between such countries in automobiles, farm machinery, computers, and other manufactured products. This dissatisfaction, however, does not extend to trade in primary products. Here, one still finds widespread acceptance of the factor endowment theory as the most useful explanation for international differences in production costs. In the words of Haberler (1977, p. 4):

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

Intuitively, the hypothesis that mineral endowment is the overriding determinant of comparative advantage in mining and mineral processing is very appealing. It also has some important implications.

First, all other determinants of comparative advantage in mining are of second order importance compared with mineral endowment. In particular, the generation and diffusion of new technology along with managerial innovations are relatively insignificant, either because the production technologies used in mining and mineral processing change little over time, or because new technologies and innovations diffuse quickly and effortlessly around the world providing little opportunity for individual mines, companies, or countries to exploit such developments to achieve a cost advantage.

Second, it suggests that comparative advantage in mining and mineral processing is largely a transitory gift of nature. Countries with the best deposits and the lowest production costs are the most competitive in world markets. Once their deposits are exhausted, comparative advantage shifts to those countries with the next best deposits. From time to time, new discoveries may also produce shifts in comparative advantage.

Third, and a corollary of the second, corporate managers and labor can do little to maintain or enhance the comparative advantage of a particular mine. As long as quality reserves remain, the mine is competitive. When those reserves are gone, the mine will be closed. The one way managers can maintain the comparative advantage of their company is by ensuring that new high quality deposits are discovered or otherwise acquired to replace those being depleted.

Fourth, governments of the major mineral producing and exporting countries are similarly limited in terms of the power they possess to promote comparative advantage in mining and mineral processing. They can encourage the exploration for new deposits domestically, through favorable land use policies, taxation, permitting requirements, and so on, which may slow the decline. Eventually, however, the exhaustion of the high quality domestic deposits will encourage firms to look abroad for the new reserves they need. Governments can also ensure that some of the rents or profits generated by the high quality domestic reserves are captured by the public and invested so that the public welfare can be sustained after the country's mineral wealth is extracted. They cannot, however, prevent mineral exhaustion and the ultimate loss of comparative advantage this effects.

**Purpose, Scope, and Overview**

The picture of comparative advantage and trade in the mineral sector sketched out above and derived from the factor endowment theory is largely deterministic. One exogenous factor (mineral endowment) governs the evolution over time of production and trade. Other than developing new high quality deposits, management, labor, and governments can do little to reduce their relative costs and enhance their comparative advantage.

The pages that follow call into question this view of mineral trade and production by drawing on the experience of the U.S. copper industry over the past several decades. This experience suggests that mineral producers play a much more important role in determining their own fortunes than the factor endowment theory suggests.

The next section describes the decline and revival of the U.S. copper industry over the past 25 years, one of the more dramatic turnarounds in mining history. The following section examines the underlying reasons for the recovery, while the final section highlights the implications for the mining industry and for international trade in mineral products.

**Decline and Revival**

In 1970, the United States mined more copper than any other country, accounting for over 30 percent of western world output (Table 1). Over the following 15 years, however, the industry's very survival was threatened. The real price of copper fell from 1.83 (1990) dollars per pound in 1970 to 0.80 dollars per pound in 1985, a price below the breakeven costs for many domestic mines. As unprofitable mines curtailed production or closed completely, output shrank. The country's share of western world output dropped to 22 percent in 1975, 20 percent in 1980, and 17 percent in 1985.

The industry twice petitioned the government for protection under the Trade Act of 1974—first in 1978 and then again in 1984. Both times its request was denied. The government maintained protection would cost more jobs in the copper fabrication industry than it would save in copper mining and processing. Skeptics noted that, unlike the steel industry which did receive protection, the copper industry was concentrated in a few.

**Table 1. Mine Output, Share of Western World Output, Net Exports, Average Breakeven Costs, and Prices for the U.S. Copper Industry, 1970, 1975, 1980, 1985, 1990 and 1995**

| Year | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 |
|---|---|---|---|---|---|---|
| Mine Output[a] | 1.56 | 1.28 | 1.18 | 1.10 | 1.59 | 1.89 |
| Output Share[b] | 30 | 22 | 20 | 17 | 22 | 23 |
| Net Exports[c] | -0.12 | -0.06 | -0.39 | -0.19 | 0.07 | -0.08 |
| Average Costs[d] | 1.01 | 1.00 | 1.08 | 0.76 | 0.67 | 0.62 |
| Average Price[e] | 1.83 | 1.43 | 1.57 | 0.80 | 1.23 | 1.19 |

**Notes:**

[a]Mine output is measured in millions of metric tons of contained copper.

[b]Output share is the ratio of U.S. to western world copper mine output multiplied by 100.

[c]Net exports reflect U.S. exports of copper minus U.S. imports of copper contained in ores, concentrates, blister, and refined metal, measured in millions of metric tons.

[d]Average costs are the weighted average breakeven costs for U.S., measured in real (1990) U.S. dollars per pound. Breakeven costs include the costs of producing copper to refined metal minus capital costs, byproduct credits, and any premium above the average western world market price for copper that U.S. producers receive. The figure shown for 1995 is actually for 1993.

[e]Average price is the average U.S. domestic producer price, measured in real (1990) U.S. dollars per pound.

**Sources:**

Mine output, output share, net exports, and prices: *Metal Statistics* (Frankfurt am Main: Metallgesellschaft AG, annual); U.S. Bureau of Census; U.S. Bureau of Mines. Costs: RTZ Mine Information System.

states with relatively little political influence, such as Arizona, Utah, New Mexico, and Montana.

Nor was it just the industry seeking government assistance that saw a bleak future for domestic copper mining. The media was also pessimistic. In a cover story *Business Week* in December of 1984 declared the mining industry was dying in the United States.

During these dark days, however, a number of U.S. producers made difficult decisions that reduced costs substantially, decisions that assured the industry's survival and even led to its revival. By 1995, real breakeven costs were substantially below their

1970 level, and more importantly from the industry's point of view comfortably below the prevailing price of copper. The country was mining copper at an annual rate that exceeded by 20 percent its 1970 level. Its share of western world output was back above its 1975 level.

At the micro level, that is the level of individual mines, this remarkable revival was not a universal phenomenon. Seven of the 26 mines that produced almost all of the country's copper in 1975 had no output 20 years later, and eight had substantially curtailed their production (Table 2). The revival of the U.S. copper industry came about largely because the remaining eleven mines managed to maintain and in some cases to increase appreciably their output. Four mines--Morenci, Chino, Ray, and Bagdad--more than tripled their output over this period, while production at Bingham Canyon, the largest mine in the United States in 1975, nearly doubled.

Only two mines with no output in 1975 -- Flambeau and Cyprus Tohono -- were significant producers in 1995. Since their combined output accounted for only 3 percent of total mine production in 1995, the turnaround of the U.S. copper industry cannot be attributed to the discovery and development of new high quality deposits, an explanation consistent with the factor endowment theory.

**Reasons for Recovery**

If the discovery and development of new high quality deposits do not account for the revival of the U.S. copper mining industry, what does? This section examines four other possible explanations, which are not mutually exclusive. First, U.S. producers may have benefited from a rise in the real costs of producing copper elsewhere. Second, U.S. producers may have enjoyed a decline in the costs of copper production as a result of rising byproduct credits associated with increases in the real price of gold, silver, and molybdenum. Third, U.S. firms may have managed to reduce their costs by convincing or forcing their employees to accept lower real wages. Fourth, U.S. firms may have reduced their costs by increasing labor productivity.

**Production costs abroad** are influenced by a variety of factors--changes in exchange rates, the cost of foreign labor, the development of new high quality deposits, the closure of old high cost mines, inefficiencies associated with state owned and operated mining enterprises, among others. While an analysis of all these factors is beyond the scope of this investigation, trends in the world price of copper over the longer run provide some indication of their collective influence. In particular, if production costs outside the United States are on average rising over time, this should eventually put upward pressure on the price of copper. In the short run this pressure can be offset by a decline in copper demand caused, for example, by a downturn in the business cycle. Over the longer term, however, unprofitable copper producers are not likely to remain in operation. So eventually, if costs abroad are rising, the price of copper should follow.

**Table 2. U.S. Copper Output in Thousands of Metric Tons of Contained Metal by Mine, 1975, 1985, and 1995**

| Mine | 1975 | 1985 | 1995 |
|---|---|---|---|
| Morenci | 121.9 | 243.1 | 403.5 |
| Bingham Canyon | 167.8 | 30.6 | 307.5 |
| Chino | 51.2 | 108.5 | 156.9 |
| Ray | 46.9 | 80.9 | 149.9 |
| San Manuel | 89.1 | 88.9 | 116.9 |
| Sierrita | 82.2 | 97.8 | 112.4 |
| Mission | 103.0 | 53.4 | 101.8 |
| Bagdad | 17.8 | 78.4 | 97.2 |
| Pinto Valley | 60.5 | 78.7 | 88.7 |
| Tyrone | 70.8 | 135.8 | 67.9 |
| Cyprus Miami | 42.9 | 69.9 | 58.5 |
| Butte | 88.1 | 0.0 | 51.2 |
| Flambeau | 0.0 | 0.0 | 39.3 |
| White Pine | 68.7 | 1.1 | 33.9 |
| Superior | 38.0 | 0.0 | 18.4 |
| Cyprus Tohono | 0.0 | 5.9 | 15.4 |
| Miami East | 10.6 | 3.7 | 10.5 |
| Continental | 14.2 | 0.0 | 7.4 |
| Yerington | 30.8 | 0.0 | 6.5 |
| Silver Bell | 27.8 | 4.2 | 3.2 |
| Mineral Park | 16.5 | 1.7 | 1.4 |
| Ajo | 31.0 | 0.0 | 0.0 |
| Battle Mountain | 14.1 | 1.4 | 0.0 |
| Bisbee | 10.5 | 1.6 | 0.0 |
| Esperanza | 12.8 | 4.5 | 0.0 |
| Ruth McGill | 27.1 | 0.0 | 0.0 |
| Sacaton | 19.0 | 0.0 | 0.0 |
| Twin Buttes | 13.8 | 15.2 | 0.0 |
| All other mines | 40.9 | 36.7 | 25.6 |
| **Total** | **1318.0** | **1142.0** | **1874.0** |

**Source:** Brook Hunt and Associates Limited.

The trend in the real price of copper over the past several decades is downward (Table 1). Some recovery does take place after 1985, during the period of recovery for the U.S. industry, but the rise is not great and is likely simply to reflect the improvement in demand that occurred after 1985. This suggests that production costs abroad on average are falling, not rising, and as a result the revival of the U.S. industry required not just a decline in U.S. production costs, but a decline sufficient to more than offset the cost reductions occurring elsewhere.

**Byproduct credits** arise because copper is frequently found in association with other valuable metals—gold, silver, molybdenum, lead, zinc, nickel, and cobalt. These metals may be recovered along with the copper, and the revenues they generate can cover some of the mining and processing costs.

The available evidence, however, provides little support for the hypothesis that a surge in byproduct credits significantly contributed to the revival of the U.S. copper industry. Trends in the real price of gold, silver, molybdenum, lead and zinc, while quite volatile, show no tendency to rise significantly over the 1970-95 period, at least after the price of gold was freed in the early 1970s.

In addition, over the past several decades, U.S. producers have turned increasingly to a new production process, solvent extraction electrowinning (Sx-Ew), which is described more fully below. This process does not recover any byproducts. Only 6 percent of U.S. copper output was produced by the Sx-Ew process in 1975. By 1995 this figure had risen to 27 percent.

Finally, if revenues from gold, molybdenum, and other associated products contributed to the revival of the U.S. copper industry, we would expect to find the byproduct credits per pound of copper production rising over time for those mines that expanded over the period and as a result were among the larger U.S. producers by 1995. This, however, has not been the case. Table 3 shows the byproduct credits for the ten largest copper mines in the United States for 1993 (the latest year available), 1985, and 1975. Half of these mines received no byproduct credits in 1993. For only Bingham Canyon and Sierrita were these credits greater than 10 percent of production costs by the 1990s.

**Lower real wages**, in contrast, were important. Figure 1 shows the trend in U.S. real hourly wages in copper mining and milling over the past several decades. From 1950 to the mid-1980s, real wages rose persistently nearly doubling over this period. Between 1984 and 1989, however, they plummeted by more than 25 percent with particularly sharp declines in 1986 and 1987. During the first half of the 1990s, real wages have remained flat at levels comparable to those that prevailed in the early 1970s.

The reversal of the upward trend in real wages was achieved by various means. Phelps Dodge confronted organized labor directly, and experienced a long and bitter strike

**Table 3. Byproduct Credits as a Percent of Production Costs[a] for Ten Major U.S. Copper Mines, 1975, 1985, and 1993**

| Mine | 1975 | 1985 | 1993 |
|---|---|---|---|
| Morenci | 0.0 | 14.0 | 0.0 |
| Bingham Canyon | 33.3 | 20.1 | 45.7 |
| Chino | 0.0 | 0.0 | 3.7 |
| Ray | 0.0 | 0.0 | 0.0 |
| San Manuel | 12.0 | 10.8 | 6.7 |
| Sierrita | 24.7 | 46.0 | 20.3 |
| Mission | 10.0 | 10.2 | 0.0 |
| Bagdad | 6.2 | 13.9 | 9.1 |
| Pinto Valley | 0.0 | 7.3 | 0.0 |
| Tyrone | 0.0 | 0.0 | 0.0 |

**Note:** [a]Production costs are breakeven costs, as defined in Table 2, plus byproduct credits.
**Source:** RTZ Mine Information System

during 1983 at its properties in Arizona. It continued to produce during the strike, and ultimately union members who fought the elimination of cost-of-living adjustments and other concessions were permanently replaced.

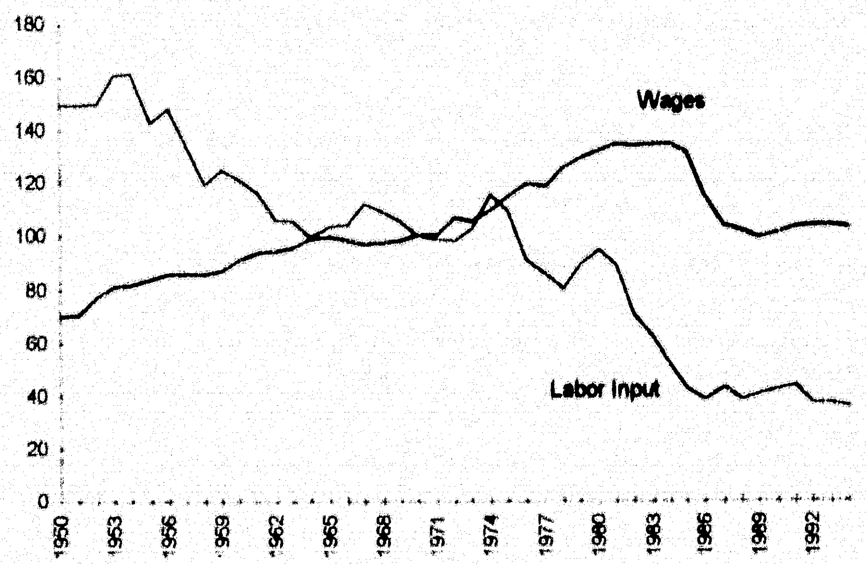
Kennecott shut down the Bingham Canyon mine in early 1985 after five years of consecutive losses. The company commenced a $400 million modernization program later that year. The union agreed to a new contract the following year that gave management much greater flexibility in work rules and staffing assignments as well as an average 25 percent cut in salary and benefits. According to the president of the United Steelworkers of America Local 392 at the time (Hamilton, 1988, p. 1):

> We paid dearly to come back to work, but we had to do it. Changes had to be made. . . . I think we did the right thing, but a lot of people think we sold out to Kennecott.

Some companies, including Magma Copper and Inspiration Consolidated Copper, helped convinced workers to accept a reduction in salary and benefits by offering profit sharing plans tied to the price of copper. Some of these arrangements produced sizable bonuses in the late 1980s when copper prices rose sharply (Regan, 1988, p. 1).

At the White Pine Mine in northern Michigan, the union's hard line against any concessions led to a strike in 1983. The mine remained shut for two years. During this period, the mine's owner, Louisiana Land and Exploration Company, sold it along with the other assets of the Copper Range Company to Echo Bay Mines, which in turn sold the White Pine Mine to the workers themselves led by a former president of the Copper Range Company. In return for a share of the company and perhaps more importantly an opportunity to return to work, workers accepted a cut in pay of nearly $4.00 per hour, or about 33 percent (McDaniel, 1989). In addition, the cost of living adjustment was dropped. While these conditions caused some consternation at the time, most workers realized the old pay schedules were no longer feasible. Moreover, four years later when the mine was sold to Metallgesellschaft, the large German mining company, the average worker received $60,000 for his ownership shares (Stertz, 1989, p. 14).

**Figure 1. U.S. Real Hourly Wages and Labor Input per Unit of Output for Copper Mining and Milling, 1950-94 (1970 = 100)**




**Source:** U.S. Bureau of Labor Statistics.

**Rising labor productivity** is the second critical ingredient in the successful revival of the U.S. copper industry. Figure 1 shows the number of hours of labor required to mine and concentrate copper in the United States over the 1950-94 period. The downward trend is striking, particularly during the 1980s. This sharp drop, however, is clearly part of a persistent and long-run trend.

Over the 1970-94 period, labor requirements per ton of output fell by 64 percent, suggesting that one worker in 1994 was producing about the same amount of copper as three workers in 1970. Most of this increased productivity occurred during the 1980s when many mines were losing money and had to cut costs or close.

While here is not the place to describe in great detail the forces behind the sharp rise in labor productivity during the 1980s, it should be noted that there was not one overriding factor, one silver bullet. The avenues to greater productivity varied from mine to mine. At any particular mine, they typically encompassed many different activities, often pursued simultaneously.

Some companies increased productivity by closing down high cost mines. Phelps Dodge, for example, deliberately shut down its Ajo mine, mill, and smelter, and invested its available funds and efforts into two other, more promising properties—Tyrone and Morenci. (Interestingly, there are now plans to reopen Ajo.)

At both Tyrone and Morenci, Phelps Dodge also promoted the use of solvent extraction electrowinning (Sx-Ew) technology, an alternative to the traditional processing technology of mining, milling, smelting, and refining.[2] The Sx-Ew works best with oxide ores, traditionally found at the weathered surface and removed as overburden at open pit mines, though it can and is used with sulfide minerals as well. The process normally involves leaching existing mine dumps or prepared ore heaps with a weak acidic solution. The solution is recovered by mixing an organic solvent with the leach solution, which selectively removes the copper. This results in a highly concentrated and relatively pure electrolyte that can be processed into high quality copper by electrowinning. The actual operation of the SX-EW is quite complex, and over time new technologies have extend the range of applications for this processing technique and greatly improve the quality of the final product.

The Sx-Ew process, where suitable, entails far lower operating and capital costs. As a result, production costs per pound of copper can be one-third or even more below those of the traditional technology. Phelps Dodge began producing copper with the Sx-Ew process at Tyrone in 1984 and ceased using the traditional technology at this mine in 1993. At Morenci, the use of SxEw began in 1987 and accounted for over half of that mine's total output by 1995.

U.S. producers have pioneered the development and use of the Sx-Ew technology. In 1994, some 54 percent of the world's Sx-Ew capacity was located in the United States, and accounted for over a quarter of that country's copper output (Chlumsky and Wallis, 1996, p. 7). In addition to Phelps Dodge, Asarco has invested heavily in Sx-Ew

[2] The traditional technology takes sulfide copper ore from the mine, and then in the mill crushes the ore and separates out the copper minerals by flotation. The resulting concentrate is roasted at the smelter, and then purified by electrolysis at the refinery.

operations at its Ray mine, Cyprus-Amax Minerals at its Cyprus Miami mine, and Magma Copper at its San Manuel and Pinto mines.

Other advances came from greater flexibility in work rules and manning assignments, which many companies won in labor negotiations along with the reductions in real wages and benefits discussed earlier. At Morenci, Bingham Canyon, and elsewhere the ore handling system was modernized. Rail haulage, once favored in large mines for its ability to handle greater tonnages, was replaced by increasingly large trucks as well as in-pit mobile crushers and conveyor belts. Computerization of truck scheduling and processing in the mill produced significant efficiencies at some sites. Changes in mine plans and work schedules helped at other operations. The use of larger trucks and drills along with more cost effective explosives also contributed savings. Indeed, part of the reduction in costs may simply reflect overall economies of scale as the U.S. copper output came from a smaller number of much larger mines.

In short, once denied government protection, the U.S. copper industry, or more specifically, that part of the U.S. that survived, largely saved itself. It did so by actively pursuing a myriad of innovative activities – some involved new arrangements with organized labor, some involved the development and use of new technologies, some involved much more modest advances whose collective impact nevertheless was substantial.

**Conclusions**

U.S. copper mining industry, for most of the 20th century the world's largest, was rapidly losing its ability to compete at the beginning of the1980s. Its share of world output was collapsing, and the gap between the market price and breakeven costs had narrowed precariously. Net copper imports were on the rise, and a number of mines were in the process of shutting down. The major producers twice beseeched the government for help.

By the end of the 1980s, however, the industry was clearly on the road to recovery. Output was up sharply, and its share of world output was bouncing back. Breakeven costs were nicely below the prevailing market price, and imports were on the wane. Some of its major mines were among the lowest cost producers in the world.

This remarkable recovery was not the result of government protection or assistance. Nor was the industry saved by a fortuitous rise in the costs of foreign producers, or in the prices of gold and other associated byproducts of copper production.

Rather the industry saved itself by pursuing a variety of cost-reducing activities that for the most part increased the productivity of labor, which rose nearly three fold during the 1980s alone. The particular measures pursued differed from mine to mine. Moreover, the new-found prosperity was not universally shared. About half of the country's mines closed or substantially curtailed production over the 1970-95 period. At the other end of the spectrum, Morenci, Bingham Canyon, and several other mines greatly increased their output. Today a number of these mines are among the lower cost producers worldwide.

A few clouds, it should be noted, do cast some shadows on this success story. First, the recovery did incur costs, some of which were probably inevitable. The cutbacks and closure at a number of mines have already been noted. In addition, even at the successful mines -- mines that managed to maintain or expand production--many workers lost jobs and those who managed to stay on saw their real compensation decline to its 1970 level.

Second, the U.S. industry is clearly enjoying a renaissance, but for how long the specter of decline can be held at bay is less clear. U.S. producers, it was argued above, did not benefit from a rise in the average costs of production abroad. It is now clear, however, that the trend toward state owned and operated mining enterprises during the 1960s and 1970s kept costs in some foreign countries considerably higher than they would otherwise have been during the 1980s. As the trend back toward privatization proceeds, costs in a number of foreign countries may fall rapidly over the coming decades. In short, the continuing success of the U.S. producers is likely to require that they maintain their growth in productivity at a pace comparable to that enjoyed over the past decade and a half.

This brings us to the main point or purpose for recounting in such detail the recovery of the U.S. copper industry. If we start with the factor endowment theory to explain international trade in mineral commodities, we are implicitly assuming that mineral endowments are of overriding importance in determining relative costs and comparative advantage. The interesting issues are then how long the endowment will last and how to divide the resulting economic rents among workers, equity holders, the state as a whole, and other interested parties. From here, one moves on to concerns over sustainability and the complexities of green accounting.

On the other hand, if extending mineral endowment through the development of known marginal deposits or through exploration and the discovery of intra-marginal deposits is not the overriding determinant of costs, but simply one of many avenues mineral producers persistently pursue in a never ending struggle to reduce costs, the set of interesting issues changes. The whole process becomes much more endogenously driven. There are still economic rents to be captured, but they are not free gifts of nature waiting like the ripe fruit of a wild cherry tree to be picked. Rather they now have to earned by engaging in that never ending struggle to reduce costs. Only firms that are consistently more successful than their competitors will survive to enjoy any economic rents their cost-reducing efforts generate.

In this scenario, managers and workers are not bystanders helplessly watching external forces unravel their predetermined fate, but instead are critical players who through their own innovative efforts have considerable control over their destiny. In this scenario, the role of government shifts from ensuring society as a whole gets its fair share of the externally given rents and that these are used in a manner that ensures intergenerational equity, to providing an economic climate that encourages the innovative activities of firms and individuals. In some instances, this may mean denying requests from domestic producers for protection. In other instances, it may require a legal and fiscal environment where innovative firms and individuals can retain most of the rents their efforts produce.

In this scenario, human ingenuity can keep the real prices of mineral commodities falling indefinitely, making concerns over sustainability and intergenerational equity less pressing. In addition, the forces shaping comparative advantage in the production of mineral commodities are not all that different from the forces determining which firms and countries will produce and export many manufactured goods and services.

The story of the U.S. copper industry is interesting precisely because it demonstrates that the second scenario can, at least in some instances, be more relevant and useful in understanding the nature of production and trade for mineral commodities than the traditional paradigm based on the factor endowment theory. Moreover, while the dramatic turnaround of the U.S. industry may be exceptional, the experience of this industry may not in other respects be all that unusual. Around the world, mineral companies are constantly searching for new technologies and other innovations to reduce costs, knowing that maintaining competitiveness in the future means producing at ever lower costs. The discovery and development of high quality deposits is only one of many possible means of reducing costs, and often may not be the most important.

## References

Andrews, David H., Jr. 1989. "Cost Reductions by U.S. Mineral Producers: Real or Illusory?" Unpublished MS thesis, Mineral Economics Department, Colorado School of Mines, Golden, Colorado.

Chlumsky, Gregory F., and Toni L. Wallis. 1996. "Sx/Ew: Technology, Quality and Cost Update," unpublished paper prepared for Metal Bulletin 9th International Copper Conference, April 16.

Haberler, Gottfried. 1977. "Survey of Circumstances Affecting the Location of Production and International Trade as Analysed in the Theoretical Literature," in Bertil Ohlin and others, eds., *The International Allocation of Economic Activity* (New York: Holmes and Meier Publishers.

Hamilton, Martha M. 1988. "U.S. Copper Industry is Lesson in Survival," *The Washington Post*, January 17.

McDaniel, Kirk Haley. 1989. "The New Copper Range Company: Its Regeneration and the Factors Influencing It," unpublished MS thesis, Department of Mining Engineering, Colorado School of Mines, Golden, Colorado.

Regan, James G. 1988. "Miners Share $10M at Two Copper Firms, *American Metal Market*, June 27.

Stertz, Bradley A. 1989. "A Once-Poor Town Gets a Lot of Advice Now That It's Rich," *Wall Street Journal*, June 29