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# Evaluating the Economic Significance of Polymetallic Sulfides Deposits

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## ABSTRACT

The current economic significance of ocean ridge polymetallic sulfide deposits is evaluated. Present and future sources of demand and supply for the contained metals are considered along with the potential for and conditions likely to foster substitution away from their use and the implications of technical change for production costs over time. Estimates of future value are discounted into present terms. International legal and political parameters are examined. The deposits appear to have negligible present resource value, but knowledge about them is valuable in itself.

## INTRODUCTION

This paper is a report of work in progress. The goal of our research is to define more carefully and systematically the current economic significance of marine polymetallic sulfide deposits at submarine crustal spreading centers (PMS). The purpose of the paper is to detail the major components of our analysis and to provide suggestive evidence for our tentative conclusions.

Table 1 presents some general information describing the PMS deposits thus far discovered, including an indication of the percent weight of four major metals contained in assayed samples. Beyond zinc, copper, lead and silver samples have also been shown to contain iron, manganese, cadmium and trace amounts of other metals, however, these metals do not appear to exist in sufficient quantities to warrant particular economic consideration.

Although little is known about the processes that generate polymetallic sulfides, there are two factors that characterize general types of deposits. One involves the distinction between zinc-rich and copper-rich areas. Most known deposits appear to align themselves along a copper-zinc continuum with silver being more directly associated with zinc-rich areas. The other involves a consideration of the size of a deposit. Most known deposits consist of relatively small chimneys (3-10 meters) of PMS sitting atop disaggregated mounds of sulfide material. However, the deposit discovered by Malahoff (1982) appears to be several times larger than any other yet found.

As Cooper (1977) has noted, "a potential resource takes on economic value only when it is in practice accessible and when it is not in infinite supply." By this quite proper standard, PMS currently have negligible economic resource value. They are not in infinite supply, claims of their renewability notwithstanding. But they are in practical economic terms inaccessible, and they will remain so until a great deal more time and other resources are spent on science, exploration, testing, and technological development and until society places greater value on the metals they contain. Zimmerman (1964) puts it: "Resources are not, they become."

## ALTERNATIVE APPROACHES TO ECONOMIC SIGNIFICANCE

Three alternative conceptual approaches are considered here: (1) addition to net surplus; (2) in-place value; and (3) net present value or rent.

Addition to net surplus is the value we would ideally like to find, as it provides a direct measure of the improvement in everybody's welfare produced by PMS (assuming everybody gets equal marginal subjective benefits from income). "Consumer surplus" is just the area bounded by market price and the downwardly-sloping demand curve in a familiar supply-demand diagram. Similarly, the area between market price and producers' marginal cost or supply curve is called "producer surplus." The sum of consumer and producer surpluses is what we mean by "net surplus," and we would like to know how PMS adds to that value.

Because of the extreme uncertainty about PMS prospects, though, and the overwhelming importance of other factors in determining demand and supply, there is little chance that this effect could be detected in even the most sensitive existing empirical estimation procedures. In any case, we have been unable to find evidence that PMS discoveries have as yet resulted in any alterations in either short-run or long-run aggregate supply and demand functions.

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References and tables at end of paper.

In-place value is the most immediate and the most potentially misleading indicator of PMS's economic significance. It is, as in equation (1), simply the mass, M, of material in a deposit or class of deposits times the percentage grade of contained metal, $g_i$, and perhaps a percentage recovery factor, $r_i$, times the current market price for the metal, $p_i$, summed over the number of recoverable metals, n.

$$IPV = \sum_{i=1}^{n} g_i M r_i p_i \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Reports of in-place value for PMS deposits have appeared in the literature, as with Cruickshank's (1982) estimate of nearly $4 billion for the Galapagos deposit (Table 2). No attempt is made to account for the cost of recovery or of the time lag before recovery is attempted. It is a measure of the contained metal's value assuming implicitly that recovery is costless and immediate. By this method a solid ton of zinc sitting in a London warehouse would show the same value as 100 tons of one-percent-zinc pyrrohtite buried deep in a mountain on Mars. In-place value may be useful as a starting point against which to weigh cost estimates for prospective commercial valuation, but it can be dangerously misleading. In fact, many experienced explorationists refuse to employ the concept and disregard estimates framed in such terms.

Net present value and rent are sometimes equivalent measures of the premium society is willing to pay (in foregone consumption of other things) in order to employ a particular resource rather than go to alternative sources. Rent is the residual return to a resource after all costs, including the return to capital and risk, have been subtracted from market price (Ricardo, 1817). The problem with rents is that they are usually not observable (Devarajan and Fisher, 1982), but they probably bear a close relation to discovery costs. So it may be possible to infer rent on the basis of observed discovery cost (Pindyck, 1978; and Devarajan and Fisher, 1982). This is a line of inquiry that may yet prove fruitful for assessing the significance of PMS. At this writing, however, we can report little progress on that front other than to observe that American industry has apparently spent zero explicitly to explore for PMS.

The net present value of PMS is just a sum of money in today's dollars that future profits from PMS are worth. That is, take all the future revenues to be earned by PMS, subtract all the costs incurred in generating those revenues, including a risk-adjusted competitive return to capital, and discount to present dollar terms. The result is net present value (Equation 2).

$$NPV = \sum_{i=1}^{n}\sum_{t=0}^{h} \frac{1}{(1+d)^t}\left((g_i M r_{it} P_{it}) - (X_t + D_t + R_t + B_{it} + S_{it})\right) \ldots (2)$$

Where:

$g_i$ = grade of ith of n contained metals
$d$ = social rate of discount
$t$ = time period of h+1 periods
$M$ = mass of deposit
$r_{it}$ = recovery factor for metal i at time t
$P_{it}$ = price of metal i at time t
$X_t$ = exploration cost at t
$D_t$ = development cost at t
$R_t$ = ore recovery cost at t
$B_{it}$ = beneficiation and processing cost for i at t
$S_{it}$ = all other sales and marketing costs, including transportation, for i at t.

NPV is equivalent to the expected top bid for exploitation rights resulting from a competitive auction for those rights. Hypothetically, direct evidence of PMS current value could be obtained by staging such an auction. As that seems unlikely, we note a rule of thumb typically applied in mineral industry property valuations: estimation of earnings can often by truncated at 20 or 25 years in the future since the discounted value of earnings beyond that period is likely to be negligible (Raymond, 1964). Applying this rule to PMS again points to negligible present resource value if, as seems probable, PMS earnings commence only after 20-25 years.

## PRICE FORECASTS

Price is a good summary statistic for a host of demand and supply conditions, and several methods are used to make price forecasts (Wat, 1982). Barnett and Morse (1963) find secularly declining real prices for mineral commodities in spite of growing demand and expect the trend to continue. More recent evidence suggests that depletable resources follow a "rather shallow U-shaped" secular time path, with a slight upward trend since the end of the interwar period (Heal, 1981; and Slade, 1982). The major weakness of trend projections is that they omit a great deal of other available information on factors likely to determine future supply and demand, and thus price, consumption and production.

## CONSUMPTION AND SUBSTITUTION

Three factors, aside from global catastrophe, threaten long-run demand for metals in PMS: (1) slow economic growth or secular stagnation; (2) substitution by other materials; and (3) metal-saving innovations in end-use. Forecasting models do a decent job only with the first of these factors, and input-output models are especially limited in handling the other two.

Copper, for example, is used mainly in electrical applications but also in pipes, in chemicals, and in heat exchangers. Aluminum is a fierce competitor in much of copper's market, though, and great reductions in copper consumption could be achieved readily by substituting aluminum. Non-metallic conductors called synmetals also show promise. Great progress in being made too on copper-saving end-use innovations. Several of these point to huge reductions in copper consumption by the communications industry: replacement of copper cables by optical fiber cables; elimination of cables through microwave transmission; equipment changes allowing use of thinner gauge copper cable; and miniaturization of circuits and equipment. On the other hand, there is some promise of new markets for copper in solar energy and electric vehicles (which may use five times as much copper as conventional vehicles).

Lead and zinc also face serious long-run demand reductions in their current uses. Ninety percent of zinc use is in zinc-alloy die castings (primarily automotive), galvanizing iron and steel, and in brass.

There are few strong substitutes in galvanizing, but plastic coatings, paints, electroplated cadmium, and galvalume (an alloy replacing zinc with 55% aluminum) compete in corrosion protection. Aluminum and magnesium are the major substitutes in diecasting, and great savings are being gained by use of lighter, thin-walled die casts for automobiles. The move to smaller, lighter autos has also reduced zinc consumption. Lead, often a co-product with zinc, has been suffering too, in part because of its toxicity and weight. Its main use, in automotive lead/acid batteries, is severely threatened by lighter more efficient sodium-sulfur or lithium- or sodium-water batteries. Its second major use, as a gasoline anti-knock additive is being sharply curtailed by environmental regulation. Also, lead's use in hot-type printing is quickly disappearing. Possible sources of future demand support for lead are electric vehicles and radiation shields. Retardation of demand growth for these metals obviously will postpone the time when they will be recovered from PMS.

In view of these conditions, the projections of cumulative world consumption made by Leontief et al. (1982) are almost certainly large over-estimates. Their input-output approach is particularly ill-equipped to capture substitution and innovation effects. Nonetheless, we choose to present the Leontief estimates here for the very reason that they project the greatest rate of increase in consumption of all the available models (Table 3). Table 4 shows the Leontief estimates of cumulative consumption of copper, zinc and silver to the year 2030.

## COMPETING SOURCES AND FUTURE SUPPLY

Evaluation of PMS economics also requires information about the relationship between prospective supplies from PMS and those from competing sources of the metals. Ideally we would like a long-run supply schedule showing the amount and source of each metal that could be brought to market at each price. Unfortunately, such information does not exist. Table 4 shows U.S. Bureau of Mines estimates of world reserves, and identified and hypothetical resources in known districts (including reserves).

Comparing the estimates for identified and hypothetical resources as of 1980 to the Leontief et al. (1982) projections of cumulative world consumption appears to indicate exhaustion of lead, zinc, and silver in 2010. Copper is still not exhausted by 2030, and only about 85% of these copper resources are consumed by that time even under pessimistic assumptions about population growth.

Assuming a fixed stock of resources in this context is unrealistic however. Over the past 25 years, world reserves of bauxite, for example, increased 1,000 percent and those of lead 433 percent (Tilton, 1977). Much of this increase came from newly discovered deposits, and resources have been increased apace. Clearly, as metals become increasingly scarce their price will rise, creating new reserves and provoking exploration, substitution, recycling, innovation and doing without. Also, it may for some time prove less costly to introduce recycling innovations than to open up unconventional sources such as PMS. Secondary copper has averaged about 15 percent of refined copper production, for example, and secondary recovery of lead accounts for about a third of that market. In other words, the techniques for recycling are already in place and only incremental changes need be made to increase their output. The limit on their use is cumulative production and the rate of turnover, which depends in part on the durability of end products.

In any event it is clear that the amount of identified stocks of metals in known districts tells only a portion of the long-run supply story. The effect of relative technological change on comparative cost will probably have as much to do with the timing and scale of a new source's entry as will the remaining stocks of identified material.

## COUNTING COSTS

Cost projections are as problematical as any element in the PMS NPV calculation. Time series help little being based on operations in an entirely different setting. Cost for existing marginal operations or new projects give a lower bound, but it turns out to be little more than a grade-weighted average of the recovered metals' prices. The frame of reference used so far seems to be cost estimates for seabed manganese nodules (Van der Voort and Mielke, 1982). Inevitably, resort must be made to engineering design concepts and cost estimates. That is an approach we are pursuing. Engineers, however, have somehow gotten a reputation in such exercises for under-estimation of cost.

Discovery costs will be high because of the necessity to use ships and rare high-technology sensing equipment. If we conservatively take $300,000 as the cost of finding the Galapagos "prospect" (Malahoff, pers. comm., 1983), and apply the onshore rule-of-thumb that one prospect in a thousand proves commercial, that suggests an average discovery cost of $300 million. Yet there is no reason to expect real PMS discovery costs to increase, and with scientific advance they would probably fall rapidly. Meanwhile, real onshore discovery costs have been increasing, perhaps doubling in the past 30 years (Harris and Skinner, 1982). Increasingly, there is reliance on theory to target search, and the theory of PMS location and genesis is progressing rapidly. PMS deposits may be "lined-up" in a predictable distribution along the mid-ocean ridge or some other easily traced setting.

Proving the deposits presents a problem. No drilling or coring has been achieved on any PMS deposit, much less the kind of close-space systematic drilling used to measure commercial prospects. Efforts are being made by the U.S. and Canadian governments to arrange a joint experimental drilling project using a Canadian drill and U.S. platform. For comparison, we note that on average offshore oil drilling is nearly three times as costly as onshore.

Mining costs for PMS are unknown, as are mining methods. Welling (1982) states, "the equipment to mine the sulfides does not exist, but the required component technology does exist...." Most speculation on method involves breaking, scraping and lifting concepts, but some kind of in-situ leaching method is also being discussed. Relative to the mining cost of seabed manganese nodules, PMS are likely to afford savings from higher grade material and more concentrated deposits. On the other hand, the need to break hard rock in PMS may add substantial cost. For the mining stage of a pioneer nodule operation, Flipse (1982) gives as a base case cost estimate $295 million (1980 dollars) capital funding and $69 million annual operating cost.

Transportation costs are likely to be equivalent on a per-ton-mile basis to those for nodules, but there may be savings associated with shorter distances between minesites and on-shore receiving facilities. Flipse (1982) cites $204 million (1980 dollars) for nodule marine transportation and terminal capital funding and $24 million annual operating cost.

Processing and delivery costs can, for present purposes, be treated as equivalent to onshore sources'.

R&D and technical change will have a direct effect on the relative economics of PMS metals versus competing sources. That is, the value and timing of entry of PMS will depend not only on the rate of improvement in knowledge and methods for PMS recovery but also on the pace of technical change in a vast complex of other areas. These include recovery from onshore deposits, production of substitute materials, adjustments in final product consumption patterns, and metal saving process innovations. There is no obvious reason to expect the relative pace of PMS technical change to outstrip these others, except perhaps the excitement of the science being done and national defense interests in gaining relative operating advantage in relevant marine technology. Over $250 million has been invested in technological R&D by the nodule mining consortia, and they are still many years away from commercial production.

The cost of time exerts a major influence on the present value of PMS because of the long time span likely before their entry. Even very large future values collapse quickly when discounted to present value over long time spans. Table 5 shows, for example, what happens if the $4 billion Galapagos in-place value is discounted at selected rates with asset liquidation various years in the future.

Interesting insights can be gained with this table. Assume the $4 billion "asset" can with certainty be costlessly recovered and instantly sold fifty years in the future. Even if the asset value is discounted at only 2% p.a. (arguably an appropriate measure of the real social rate of discount), its present value is only $1.49 billion. Because the value of the contained metals will most likely vary with world economic prosperity, PMS is a socially risky asset. So a higher discount rate may be more suitable, say 10%. If we let the real grade-weighted average metal price increase 5% p.a., then the net discount factor is 5%. $4 billion in 50 years, discounted at 5% p.a., collapses to $350 million in present value. Recall that this is based on zero recovery costs and perfect certainty. If we account for cost by letting rent equal 10% of gross value and tag a conservative 10% uncertainty premium on the discount rate, the present value of the $400 million rent at liquidation in 50 years is less than half a million dollars. If the liquidation occurs in 100 years, the present value of the rent is $340.

These figures are for illustration only and are not intended to portray the actual present resource value of the Galapagos deposit. They are suggestive, however. As we interpret them, they tend to support the conclusion that, given existing uncertainties, the present resource value of PMS is indistinguishable from zero.

## JURISDICTION AND REGULATION

The commercial exploitability of PMS will clearly be influenced by the nature of the regulatory regime under which proposed exploitation would be carried out. Given the physical characteristics of the PMS depositional environment and the present uncertain marine legal environment four different jurisdictional scenarios must be reasonably developed. These are driven by a consideration of whether PMS exploitation activities are carried out: 1) inside U.S. jurisdiction; 2) inside another coastal state's jurisdiction; 3) outside national jurisdiction but controlled by the International Seabed Authority under the provisions of the U.N. Convention on the Law of the Sea; and 4) outside national jurisdiction but licensed and/or regulated by a multilateral agreement other than the Convention.

It is likely that a different set of regulatory mechanisms will exist within each of these jurisdictional regimes, but each will probably take into account the following issues. A primary question is whether or not a potential PMS miner will have to lease rights for PMS resource development or will merely be licensed to carry out exploitation activities. If exploitation rights are leased, then the size of the leased area becomes an intriguing question. Based on the cost assumptions herein presented and the distribution of known sulfide deposits it is possible that a mining area could stretch a few thousand kilometers along a ridge system. If this were the case mining operations could well be complicated by the fact that they would be carried out under different and perhaps conflicting jurisdictional and regulatory regimes. Activities initiated outside U.S. jurisdiction may have to deal with questions of the transfer of mining technology and of exploration data.

Further, given the current state of our knowledge of the hydrothermal vent areas, it should not be assumed that environmental concerns will be excluded when defining development regulations. We know little about the distribution of the unique animal habitats colonizing vent areas, and significant amounts of work remain to be done before the environmental impact of mining operations can be rationally stated.

It is impossible to characterize precisely the regulatory mechanisms that would emerge for PMS development. However, because deposits appear to exist both inside and outside national jurisdiction, we suggest that such rules would be diverse and probably idiosyncratic.

## LEARNING EFFECTS AND SOCIAL INVESTMENT

It is important to distinguish between the value of knowledge about PMS deposits and the resource value of the deposits themselves. Though the latter appears to be negligible, knowledge about PMS seems to be of significant (if hard to measure) value. In the U.S., productivity of conventional prospecting methods has fallen dramatically. Reliance has shifted increasingly to methods based on geologic inference. Information on the genesis of mineral deposits and their settings can be critical to the success of these methods. It is as an observatory for such information that PMS deposits are of most value. Indeed, close study of these "time-zero" mineralizations and the hydrothermal activity that generates them should foster improved inferences about such basic mysteries as geotectonic processes and the globe's thermal and geochemical dynamics. Further, development of technologies to aid the scientific enquiries will have the spillover effect of generally advancing human capability to function in a hostile environment.

Many economists have long recognized that the productive benefits of scientific research, though universally acknowledged, are hard to tie down and usually even harder to tie to particular theories or discoveries. This has led to discussion of the "social warrant" for basic research and to the conclusion that much of science has intrinsic social value over and beyond its productive potential (Rottenberg, 1966). While this does not address the question of which scientific pursuits are most worthy, it does suggest that science of the sort thriving around the hydrothermal vents has not had to and cannot be expected to "pay its own way" in any direct or immediate sense. Basic scientific research can have tremendous social value and still not be able to support itself on its own re-invested profits. Therefore, if basic research is to continue, it must look to government and other public-spirited sources for support.

## CONCLUSIONS

Much data and surmise still need to be gathered and interpreted, but even with the sketchy evidence at hand we believe certain propositions can be supported.

1. Given current knowledge, PMS have essentially zero present value as a mineral resource.

2. Scientific knowledge about PMS deposits appears to be of significant value.

3. The two major factors driving the economics of PMS as a potential resource, other than demand for the contained metals, are: (a) the state of knowledge of the deposits; and (b) the relative pace of technological advance.

4. The location and timing of future PMS market entry would likely be influenced by jurisdictional developments that would probably result in a diversity of regulatory regimes.

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## TABLE 1

## SELECTED DATA ON DEEPSEA POLYMETALLIC SULFIDE DEPOSITS

| Area | Year of Discovery | National Involvement | Minerals Zn % | Cu % | Pb % | Ag ppm |
|---|---|---|---|---|---|---|
| Jaun de Fuca[1] | 1981 | U.S. | 54-59 | .07-.32 | .06-.25 | 230-290 |
| Guaymas Basin[2] | 1980 | US/Mexico | 30 | 1.00 | .10 | 300 |
| E. Pacific Rise[3] 21° N | 1978 | US/Mexico<br>France | 8-34 | .90-.01 | .01 | 17-45 |
| E. Pacific Rise 13° N | 1981 | France | Samples were taken but assays have not been released. | | | |
| Galapagos Rift[4] | 1981 | U.S. | 1.00 | 6.50 | .02 | 21 |
| E. Pacific Rise 20° S | 1981 | US/France | No samples taken. Evidence generated by remote sensing. | | | |

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Sources:

[1] Koski, et al. (1982). Assay range of samples considered to be most representative of material taken from the area.

[2] Van der Voort and Mielke (1982).

[3] Haymon (1982).

[4] Malahoff (1982).

# TABLE 2

## CRUICKSHANK'S ESTIMATE OF IN-PLACE VALUE FOR GALAPAGOS PMS DEPOSIT

| Metal | Value /Unit[a] | %Reported[b] | Gross $Value x10$^{6}$[c] | Estimated Recoverable[d] | $Value |
|---|---|---|---|---|---|
| Copper | 0.86/lb | 10.00 | 4.3x10$^{3}$ | 60% | 2.6x10$^{9}$ |
| Silver | 8.92/tr oz. | 0.30 | 1.6x10$^{3}$ | 60% | 9.6x10$^{8}$ |
| Cadmium | 1.8/l$^{b}$ | 0.01 | 9 | - | - |
| Iron | 80/lt | 10.00 | 0.2 | - | - |
| Molybdenum | 8.75/lb | 0.10 | 437 | 60% | 2.6x10$^{8}$ |
| Lead | 0.4/lb | 0.10 | 22 | - | - |
| Tin | 7.5/lb | 0.03 | 113 | - | - |
| Vanadium | 2.0/lb | 0.10 | 98 | 60% | 5.9x10$^{7}$ |
| Zinc | 0.5/lb | 0.10 | 24 | - | - |
| | | | | | 3.88x10$^{9}$ |
| | | | Value/Ton | | $155.20 |

a) Engineering & Mining Journal, September 1981.
b) Reported size and grades from Ocean Science News (October 12, 1981). Grades differ from more recent estimates in Table 1.
c) 25 Million tons assumed.
d) Arbitrary assumption.

Source: Cruickshank (1982)

# TABLE 3

## COMPARISON OF ALTERNATIVE PROJECTED ANNUAL RATES OF GROWTH* IN WORLD CONSUMPTION OF COPPER, LEAD AND ZINC: 1970-2000

| | Bureau of Mines | W. Malenbaum[1] | Ridker and[2] Watson | Leontief et. al. |
|---|---|---|---|---|
| Copper | 3.9 | 2.94 | 2.7 | 4.35 |
| Lead | 3.5 | - | 3.34 | 4.47[2] |
| Zinc | 2.1 | 3.05 | 2.6 | 3.53 |

* Rates of growth computed on the basis of physical units.

[1] 1975-2000

[2] Includes secondary as well as primary demand.

Source: Leontief *et al*. (1982).

## TABLE 4

### LEONTIEF ET AL. ESTIMATED CUMULATIVE WORLD CONSUMPTION COMPARED TO 1980 WORLD RESOURCES (MILLION METRIC TONS)

| | COPPER | ZINC | SILVER |
|---|---|---|---|
| 1980 Resources | 1627 | 325 | 0.7700 |
| 1980 Reserves | 494 | 162 | 0.2527 |

| | COPPER | | ZINC | | SILVER | |
|---|---|---|---|---|---|---|
| | Q | % | Q | % | Q | % |
| 1980 | 82 | 5.0 | 60 | 18.5 | - | - |
| 1990 | 216 | 13.3 | 146 | 44.9 | 0.207 | 26.9 |
| 2000 | 419 | 25.7 | 273 | 84.0 | 0.524 | 68.1 |
| 2010(O) | 693 | 42.6 | [441] | 135.7 | [0.971] | 126.1 |
| 2010(P) | 674 | 41.4 | [429] | 132.0 | [0.949] | 123.2 |
| 2020(O) | 1062 | 65.3 | [732] | 225.2 | * | * |
| 2020(P) | 986 | 60.6 | [676] | 208.0 | * | * |
| 2030(O) | 1570 | 96.5 | [958] | 294.8 | * | * |
| 2030(P) | 1383 | 85.0 | [848] | 260.9 | * | * |

Q = Projected cumulative consumption.

% = Q as per cent of 1980 world resources.

[ ] = Apparent exhaustion of 1980 resource.

O = Optimistic consumption scenario (3 percent GDP growth for developed countries; low U.N. population growth projections and agricultural self-sufficiency for developing countries).

P = Pessimistic consumption scenario (2 percent GDP growth for developed countries; high U.N. population growth projections and problems in achieving agricultural self-sufficiency for developing countries).

* Silver data incompatible with format.

Source: Leontief et al. (1982).

## TABLE 5

### PRESENT VALUE OF $4 BILLION FUTURE VALUE WITH DIFFERING DISCOUNT RATES AND TIME SPANS

| d = | T = 0 | 25 | 50 | 100 |
|---|---|---|---|---|
| 0 | 4.00 | 4.00 | 4.00 | 4.00 |
| .02 | 4.00 | 2.44 | 1.49 | 0.55 |
| .05 | 4.00 | 1.18 | 0.35 | 0.03 |
| .10 | 4.00 | 0.37 | 0.03 | 0.00 a) |
| .15 | 4.00 | 0.12 | 0.00 b) | 0.00 c) |

T = Number of years to realization of future value

d = Discount rate

a) Present value = $3 \times 10^{-4}$
b) Present value = $4 \times 10^{-3}$
c) Present value = $3.4 \times 10^{-6}$