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HIGH-GRADING IN METALLIFEROUS ORE BODIES: THE ECONOMIST'S PERSPECTIVE

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As economists with some experience in mineral economics and the analysis of mining tax policy in several countries, it has been with some interest that we have followed the recent exchange between Thomas and Walduck in Mining Magazine regarding the economic effects of "high-grading."[1] It is our purpose in this paper to contribute an economist's perspective to the problem of grade management, and to comment upon several points of the Thomas and Walduck contributions which we believe to be unclear or erroneous.

In particular, we will attempt to show that (1) while Mr. Thomas has utilized the most sensible framework for evaluating the economic consequences of high-grading (i.e., the discounted cash flow criterion), he has drawn some incorrect conclusions regarding the benefits that might result from high-grading; and that (2) while Mr. Walduck makes an important contribution in urging consideration of the effects of cyclical behavior of mineral prices, and in pointing out that other investment criteria such as payback period may in some cases merit consideration as well,[2] he utilizes another criterion which will be shown to be generally incorrect: that "low grades should be mined in times of low prices and high grades in times of high prices." He

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[1] E. G. Thomas, "Justification of the Concept of High-Grading Metalliferous Ore Bodies," Mining Magazine, Vol. 134, May 1976; C. P. Walduck, "Justification of the Concept of High-Grading in Metalliferous Ore Bodies--A Dissenting View," Mining Magazine, Vol. 135, July 1976.

[2] We would argue that the payback period criterion is, relative to the D.C.F. criteria, relevant only in those circumstances in which a mining project faces extreme political risks of expropriation.

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goes on to make the uninteresting observation that "if everybody did it [mine low grades when prices are low and high grades when prices are high] the greater the financial benefit in current money terms," and that "if everybody did it there would also be an automatic governor to regulate the supply of metal in accordance with demand."

(3) Both Thomas and Walduck, but especially the former, are incorrect in their view that a competent capitalistic manager would behave differently from a competent socialist manager insofar as grade management is concerned. A competent socialist manager--or for that matter a competent manager of a state-owned enterprise in a mixed economy--would use a form of DCF analysis that differs from conventional DCF analysis only with respect to (a) choice of discount rate and (b) valuation of benefits and costs in terms of the value to the economy, rather than to the firm. For example, costs of capital, labor and other resources would be measured at their social opportunity costs, not necessarily at market prices. This fundamental point has been extensively treated in the cost-benefit literature of the last decade.[1]

The Economic Consequences of High-Grading

Mr. Walduck notes that because opportunities for high-grading a given ore body are restricted by the additional costs required by such a strategy, occasions where high-grading may be feasible are not all that numerous. He is perhaps correct in this observation; however, we are aware of several situations in both underground mining and in open-cast operations where high-grading

[1] For example, M. Roemer and J. Stern, The Appraisal of Development Projects, Praeger, 1975, Ch. 1.

is technically feasible.[1] Thus, there is a need for the type of careful analysis undertaken by Mr. Thomas in his note.

The prime concern of environmentalist critics of a high-grading policy is that low-tenor ores bypassed now may never be recovered. While high-grading may appear to lead to a waste of resources in a physical sense, it may be the most advantageous policy to follow when the objective is to maximize either the private or the social value of the output from the mine.

Under some circumstances high-grading may generate a positive private and social benefit because the time value of money is positive. Thus, a given amount of mining profits has a greater value to both the private sector and society if it is generated currently than in the future. Even if there are some costs through loss of potential ores or additional operating expenses, it may still be socially beneficial to high-grade so long as the gain from the reinvestment of the additional revenues obtained earlier through high-grading are larger than these additional costs.

Economic Evaluation of a Mining Project

The following analysis is based on the porphyry copper ore-body characteristics and cost assumptions used by Thomas and Walduck. These characteristics are reproduced in Tables 1 and 2. We also assume the same four-year price cycle used by Walduck; that is, a cycle of four years' duration with average prices beginning at $750 per tonne, rising to $1,000 and $1,250 in years 2 and 3, and falling to $1,000 in year 4.

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[1]We have observed high-grading in the context of both underground mining (in Bolivia, where the Indian word for the practice literally means "killing the deposit," and in Indonesia, where the Dutch practiced highly selective mining of manganese deposits for forty years) and in open-cast operations (in Indonesia, where plans for exploring a large lateritic nickel deposit specifically call for high-grading in the early years of operation).

Table 1

Details of Reserves in Hypothetical Orebody

Reserve Category	Tonnage	Grade Range % Cu	Average grade % Cu
1	10,000,000	0.70 - 0.75	0.725
2	10,000,000	0.65 - 0.70	0.675
3	10,000,000	0.60 - 0.65	0.625
4	10,000,000	0.55 - 0.60	0.575
5	10,000,000	0.50 - 0.55	0.525
6	10,000,000	0.45 - 0.50	0.475
7	10,000,000	0.40 - 0.45	0.425
8	10,000,000	0.35 - 0.40	0.375
9	10,000,000	0.30 - 0.35	0.325
10	10,000,000	0.25 - 0.30	0.275
11	10,000,000	0.20 - 0.25	0.225
12	10,000,000	0.15 - 0.20	0.175
13	10,000,000	0.10 - 0.15	0.125
14	10,000,000	0.05 - 0.10	0.075

Table 2

Average Grades for Hypothetical Orebody

Reserve Categories	Average Grade % Cu
1 - 10	0.500
1 - 11	0.475
1 - 12	0.450
1 - 13	0.425
1 - 14	0.400

The problem is to select a production strategy, given these assumptions, that will maximize the discounted cash flow from the deposit. This is equivalent to picking the strategy that will maximize the present value of profits if the mine is operated by a capitalist firm, or to maximizing the present value of the social surplus if the operator is a state-owned mining company.

Rather than select an ad hoc rule such as those suggested by Thomas and Walduck to determine the strategy for mineral extraction over the life of the mine, we suggest a methodology that will enable the mine operator to derive the best production program so as to maximize the discounted cash flow for the mine.

The case used by Thomas assumes that maximum production capacity, grades, costs, and prices are known currently and for the future periods. With these variables given, we suggest that the determination of what grade of ore to produce and the timing of production should proceed as follows:

1) Determine the cut-off grade for each possible price.
2) Determine ordering of grades to be extracted so that each grade provides the maximum contribution to net discounted cash flow.
3) Determine the timing of the initial investment so as to maximize the discounted net cash flow from the mine.
4) Steps 1-3 determine the economic life of the mine.

By definition the cut-off grade is the grade at which reserves are no longer economically recoverable. At this grade the cost of output will be equal to the market price. The choice of cut-off grade is dependent on two factors: (1) the world price for processed ore, and (2) the cost per tonne of mining and processing the ore (where processing refers to costs of milling and smelting) plus any taxes geared to value or volume of gross output. In the example, we assume (a) that there are no gross output taxes (although these levies can, as shown in Gillis, et al., 1977, clearly induce high-grading themselves) and (b) that the total cost of extraction and processing is three dollars per tonne, regardless of grade. But the cost of obtaining a tonne of processed ore increases with lower grades because of the inverse relationship between grade and the number of tonnes required to obtain one tonne of metal. If the 0.725 percent grade is used, for example, then with 100% recovery it takes 137.93 tonnes of ore to produce one tonne of metal at a cost per tonne of $413.79. However, it takes 1,333.33 tonnes of 0.075 percent grade at a cost of $4,000.00 to get one tonne of pure grade. Thus, the cut-off grade can be determined by finding the grade whose costs per tonne of extraction and processing equals the market price. The cut-off grades at each mineral price in the cycle are presented in Table 3.

These cut-off grades raise some interesting issues regarding the analysis of the previous two authors. First, Thomas assumes the life of the mine is ten years with prices constant at $1,000.00 per tonne (see Thomas' Table 6). But the operation incurs a dollar loss of $2.5 million in the tenth year because the grade of the ore extracted is less than the 0.3 percent cut-off grade. Why produce in year ten if this involves a loss for the firm? Zero profit is always preferred to negative profit. Thus, in Thomas' example the economic life of the mine should be nine years and not ten. This would result in a higher net present value and an increased rate of return for the mine used in Thomas' illustration. Therefore, in order to maximize the total profit or society's surplus the maximum life of the mine should be determined by the cut-off grade and not by some arbitrary limit.

Second, the cut-off grades in Table 3 show that Walduck's criterion of taking low grades when prices are low is in general incorrect. In his examples (see his Table 5), ores below the minimum cut-off are taken in years

TABLE 3

Cut-Off Grades for Economic Extraction of Copper Ore at Each Price in the Cycle

Price of output per tonne ($ U.S.)	Cut-off grade in exploitation % Cu (G)	Cost per tonne of processed ore at cut-off grade ($ U.S.)
750	0.400	750
1000	0.300	1000
1250	0.240	1200

The cut-off grade (%) is calculated as follows:

$$G = \frac{\text{Mining, Milling and Smelting Cost per Tonne of Unprocessed Ore}}{\text{Price of Processed Ore (per Tonne)}} \times 100$$

In this example the mining and milling/smelting costs are a constant $3.00 per tonne of unprocessed ore. (From Thomas, Table 3.)

1, 5 and 9, resulting in losses for each of those years. But we show (in tables 4 and 5) that while at the peak of a price cycle the highest grade ore available is produced, when prices are low it still may pay to produce grades other than the lowest grade ore. And at the bottom of the cycle (in this example) it is best not to produce at all. Again, why mine low grades in times of low prices if all you get for your effort is a loss? From society's point of view such a policy is clearly irrational because it would imply that scarce capital, labor and energy resources should be used up to extract a mineral even if the value of the mineral is less than the value in alternative activities of the resources. From an economic perspective, when prices go up the cut-off grade goes down. Only when prices are high is it profitable to extract marginal grades. Any policy that deviates from this criterion will result in both a private loss of profits as well as a social waste of resources.

The next step in the evaluation is the determination of when in the price cycle over time should each grade be extracted. In Thomas' example where prices are constant, high grades should be taken first. However, when prices are cyclical the solution becomes more complex. For example, regardless of the price, the highest grade ore will always yield the highest profit. So the first thing to determine is the optimal time to extract the highest grade. Table 4 shows how this is done. First, determine the undiscounted net profit from production of the highest grade of ore in each possible year. Second, discount the profit by the opportunity cost of funds to the firm. Then choose the year to take the highest grade such that the greatest discounted cash flow is yielded. As Table 4 shows, the time the highest grade ore should be extracted is year 3. Why year 3? The answer is quite simple. Market prices in year 3 are 67 percent higher than year 1, but the foregone opportunity cost (or the cost of postponing production) has risen by only 17 percent. Since in the example prices are going up at a rate greater than the

TABLE 4

Determination of When to Extract
the Top Grade (0.725%) Ore

Year	Price per tonne	Net profit (in millions of $)	Discounted net profit
1	750	24.375	22.569
2	1000	42,500	36.437
3	1250	60.625	48.126*
4	1000	42.500	31.239
5	750	24.375	16.589
6	1000	42.500	26.782
7	1250	60.625	35.374
8	1000	42.500	22.961
9	750	24.375	12.194
10	1000	42.500	19.685
11	1250	60.625	26.001
12	1000	42.625	16.877
13	750	24.375	8.963
14	1000	42.625	14.470

*Extract the highest grade in year 3.

private discount rate, it will pay to defer production of that grade. In this case, ore in the ground is better than money in the bank. The next step is to repeat the above to determine in which year to produce the next highest grade (other than year three). Given that production is constrained to 10 million tonnes per year, and the highest grade ore is to be produced in year three, then the second highest grade ore makes the largest contribution to the discounted net cash flow if it is produced in year 2. Also, the remaining grades should be extracted in the year that will maximize their contribution to the discounted cash flow. For example, the third highest grade of ore is produced in year 7, while the fourth highest grade ore is produced in year 4. The procedure then continues to each lower grade until the cut-off grades are reached. This procedure will yield the optimal profits. We have developed a computer program to carry out the necessary calculations to solve for the correct exploitation strategy so that the discounted net cash flow will be maximized. The results for the example used in this paper are summarized in Table 5.

The results in Table 5 merit some discussion. First, contrary to Walduck, we note that when prices are the lowest, nothing is produced. And in no circumstances would the lowest available grades be mined in the earliest year of the project. Mining of the lowest grades will, as in Thomas' case, be postponed until the later years even when prices are cyclical.

In an actual mine, there may be some costs from not producing in years 5 and 9 (if the mine is actually closed, flooding problems, for example, could result). However, these results explain why some mines close and reopen at later dates, e.g., the recent recovery of coal mining in the Eastern U.S. and the reopening of copper mines in Italy over a few centuries.

Table 5

An Economic Strategy for the Exploitation of a Mineral Resource

Year	Initial Investment $ X 10^6	Operating charge $ X 10^6	Reserve Category Extracted*	Average mining grade % Cu	Undiscounted Net cash flow $ X 10^6	Discounted Net Cash Flow $ X 10^6
0	0	0	-	-	0	0
1	-100.000	0	-	-	-100.000	-92.59
2	0	-30.000	2	0.675	37.500	32.150
3	0	-30.000	1	0.725	60.625	48.126
4	0	-30.000	4	0.575	27.500	20.213
5	0	0	-	-	0	0
6	0	-30.000	6	0.475	17.500	11.028
7	0	-30.000	3	0.625	48.125	28.081
8	0	-30.000	7	0.425	12.500	6.753
9	0	0	-	-	0	0
10	0	-30.000	8	0.375	7.500	3.474
11	0	-30.000	5	0.525	35.625	15.279
12	0	-30.000	9	0.325	2.500	.993
TOTALS	-100.000	-270.000	-	0.525	149.375	73.507

Net present value at 8% discount factor	$73,507
Discounted cash flow return	28.755%
Life of mine	9 operating years
Average ore grade	0.525%
Total copper mined	90,000,000 tonnes
Undiscounted pay-back period	3 years

* Refer to Table 1.

Not producing in year one raises the issue of when to bring the mine on stream. Should a mine which is going to be completed for year 2 be built in year zero or 1? As the results show, investing $100 million in year zero to produce in year two only makes sense if the cost of the physical capital investments rise (net of general inflation) at a rate greater than the discount rate. The investment in idle capital in year zero forces the operator to forego short-term investments in other assets that could increase the value of the capital stock.

Walduck claims that if low grades are mined in times of low price, and high grades mined in times of high price, the greater the financial benefit, in <u>current</u> money terms. While this is true, it is also completely irrelevant. Even the most traditionally oriented management nowadays recognizes that the value of a dollar two or ten years hence is something less than the value of a dollar today. The cash flow of future years must be discounted by the opportunity cost of funds in order to make economic or financial comparisons.

The economic strategy for exploitation of this sample mineral deposit results in a net present value of $73.5 million. This is to be compared with $53.6 million, which is the result of the best strategy proposed by Walduck. This means that the net value of this mineral deposit would be 27 percent lower using the best of the non-economic strategies. This 27 percent reduction in the discounted cash flow is equal to the loss in profits to the private firm or the waste of scarce resources for the economy if a non-economic strategy is used to exploit a mineral reserve.

Capitalism and Socialism

The final issue to be discussed is Thomas' distinction between the capitalist and the socialist approach to grade management. First is Thomas' claim that capitalist managers would accept a loss in the last year of production. Why should they? By accepting losses they do increase the life of the mine, but at the cost of earning a normal return from their investment elsewhere.

Furthermore, from a socialist perspective, accepting losses in the tenth and subsequent years is irrational. For a state-run operation (like those in Indonesia, Zambia, Bolivia and Peru), prolonging the life of the mine beyond the point of economic recovery imposes a cost on society, in the form of scarce resources which could profitably be invested in other forms of social development. In fact, prolonging the life of the mine does not ensure maximum recovery; it wastes scarce resources. If the world price means anything, it measures how the market values the product. Recovery of the resource at a loss does not increase the welfare of consumers and it decreases the potential for society to make investments in other areas.

Prolonging the life of a mine for employment reasons is an equally misdirected policy, even in a socialist state. Of course such a policy would maintain employment at the mine site, but at a cost-per-job often far in excess of that which would be possible if the mine were closed and the resources released to be gainfully employed elsewhere in the economy. Nor are the alleged secondary benefits from artificially increased mine life of any economic or practical significance. For example, Thomas claims that such a policy inherently reduces the level of risk. In fact, the contrary is true, because the expected returns from increasing the life of the mine in this case are negative, thus increasing the variance of the stream of returns for the mine over time.

Neither a capitalist nor a socialist should be willing to extract the resource at a loss. Admittedly, what we have presented is only an example, but it does show the value of economic analysis in evaluating mining projects. We hope it begins an increased interchange of views between the mining engineer and the economist, an interchange which we feel can increase our mutual understanding of the problems facing the mining sector.

References

1) Malcolm Gillis et al., Taxation and Mining (forthcoming, Ballinger Press, 1977).

2) Michael Roemer and Joseph Stern, The Appraisal of Development Projects (Praeger, 1975, Ch. 1).