ON BORROWED TIME?
ASSESSING THE THREAT OF MINERAL DEPLETION

by

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Abstract

The debate over the long-run availability of mineral commodities remains today as polarized as it was 30 years ago. This partly reflects the two very different paradigms often used to assess this threat, which can lead to sharply contrasting conclusions. In addition, the uncertainties regarding future developments in mineral supply and demand, which will govern the course of real mineral prices, are great. The geological unknowns are particularly a problem in this regard. Finally, mineral commodity prices reflect only those social costs that producers pay. Just how much greater prices would be—and how their trends over time would be alter—if prices reflected the full social costs of production and use is unknown. The available estimates vary greatly, and often reflect the values of individuals and groups rather than those of society as a whole. In light of the last two uncertainties, we simply do not know whether mineral commodities will become more or less available in the long run. The optimists cannot prove the pessimists wrong, nor can the pessimists prove the optimists wrong. So perhaps the most reliable prediction about the future threat of mineral depletion is that the debate will continue.

Introduction

Concern over the adequacy of natural resources dates back at least two centuries to Thomas Malthus, David Ricardo, and other classical economists. Indeed, economics is

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widely known as the dismal science thanks to Malthus' concern that population growth, coupled with limits on the availability of agricultural land, would ultimately cause the human condition to decline to the subsistence level.

The most recent wave of concern emerged in the early 1970s, thanks in part to the widely read book, *Limits to Growth* (Meadows and others 1972). Using a sophisticated computer simulation model, *Limits to Growth* argues that the exhaustion of mineral commodities could cause the collapse of the high living standards enjoyed by the developed world by the middle of the 21st century. For many, the jump in resource prices—the result of a simultaneous economic boom in the industrial countries and in the case of oil the collusive activities of the Organization of Petroleum Exporting Countries (OPEC)—that followed on the heals of this publication provided support for its dire predictions.

Others, however, took issue with both the book's methodology and its conclusions, and a lively debate ensued that continues down to the present. At one end of the spectrum are the pessimists, often geologists and other scientists, who fear mineral depletion, particularly the depletion of oil, is a serious problem.[2] At the other of the spectrum are the optimists, often economists (in spite of the discipline's reputation as the dismal science), who see no threat, even in the distant future.[3]

Over time, the nature of the debate has shifted slightly, as the pessimists have increasingly focused more on the environmental and other external costs associated with the production and use of mineral commodities, and less on their actual availability. The

[2] See, for example, Ayres 1993, Deffeyes 2001, and Kesler, 1994.

[3] See, for example, Simon 1981, and Lomborg 2001.

social costs, many pessimists now contend, will limit the future use of mineral commodities, even if availability is not an issue.

This article makes no attempt to answer the central question: Will mineral depletion threaten the future welfare of society and make modern civilization as we know it unsustainable? Rather it contends that given the uncertainties laid out below no one knows the answer to this question. Those who argue otherwise are asking the rest of us to accept their faith, or lack of faith, that technology will in the future offset the adverse effects of mineral depletion. The pages that follow focus on the three main reasons why the debate remains so polarized despite the many opportunities enjoyed by the two competing camps over the past several decades to exchange views. How is it that intelligent people can remain so divided for so long over this issue? And, why is there no certain answer to this important question?

Paradigm Choice

Most people use one of two mental models to assess the threat of mineral depletion—the fixed stock paradigm or the opportunity cost paradigm. These models have quite different implications for the nature of the depletion process.

The fixed stock paradigm starts with the observation that the earth is finite. This means that the *supply* of any mineral commodity must also be finite, and hence is a fixed stock. The *demand* for oil and other mineral commodities, however, is a flow variable. It continues year after year after year. So it is only a question of time before demand consumes the available supply. Moreover, if demand is growing exponentially, as it has for many mineral commodities over parts of the past century, the end is likely to come sooner rather than later due to the tyranny of exponential growth.

This, for example, is the view of depletion found in *Limits to Growth*. Depletion is like a pair of mice eating away at a big piece of cheese. One day the mice (or their many descendents) are fat and happy, the next the cheese is gone, the cupboard is bare, and starvation looms.

Despite its logic and intuitive appeal, the fixed stock paradigm suffers from several fatal shortcomings. First, many mineral commodities, especially the metals, are not destroyed when they are consumed. As a result, recycling and reuse are possible. Of course, recycling in some cases (such as the lead once used as an additive in gasoline) is prohibitively expensive, but this is a question of costs, not physical availability.

Second, for other mineral commodities, particularly the energy minerals, substitution may alleviate the threat of mineral depletion. Coal, natural gas, petroleum, nuclear, hydropower, wind, and solar energy can all be used to generate electric power. The mix of resources used at any particularly time reflects their costs. If depletion drives the costs of some energy sources up, society will reduce their use and rely more on alternative energy sources.

Third, the fixed stock of many mineral commodities is huge. At current rates of consumption, for example, the copper and iron found in the earth's crust would last 120 million years and 2.5 billion years respectively. These are big numbers. For comparison, scientists estimate that the big bang occurred about 13 billion years ago, that our solar system is about 5 billions old and already halfway through its expected life, and that the human race evolved as a species only several hundred thousand years ago.

Fourth, and most important, long before the last barrel of oil or pound of copper is extracted from the earth's crust, costs would rise, at first curtailing but eventually completely eliminating demand. In short, what we have to fear is not physical depletion, where we literally run out of mineral resources, but economic depletion, where the costs of producing and using mineral commodities rises to the point where they are no longer affordable.

For these reasons, the second perspective on depletion, the opportunity cost paradigm, is more useful. It assesses the availability of mineral commodities by considering what society has to give up in order to obtain another barrel of oil or ton of copper, rather than by estimates of the remaining fixed stock. Several measures are used for estimating these opportunity costs, including production costs and the value of mineral reserves in the ground, but the most widely available and reliable are the real prices for mineral commodities. When the real price for a mineral commodity is rising over the long run, it is growing less available or more scarce.

The opportunity cost paradigm has some important implications. First, even in the absence of physical depletion, economic depletion may occur in the sense that mineral commodities become too expensive to use. However, if depletion does occur, it will occur gradually over time as the real prices of mineral commodities rise persistently, slowly eliminating the demand for mineral commodities in one end use after another. Depletion will not be a surprise. We will not wake up one day and find the cupboard bare.

Second, and particularly important for the long-run human condition, depletion—economic or physical—is not inevitable, as the fixed stock paradigm implies. While the need to exploit lower grade, more remote, and more difficult to process deposits tends to drive the costs and prices of mineral commodities up over time, new technology can offset this upward pressure. In short, the long-run availability of mineral commodities is now determined by a race between the cost-increasing effects of depletion and the cost-decreasing effects of new technology. Over the past century, the available empirical evidence indicates that this race has largely been won by new technology, as the long-run trends in real prices for most mineral commodities have either declined or remained the same.[4] Of course, the past is not necessarily a good guide to the future, and we have no guarantee that such benevolent trends will continue indefinitely.

Third, population growth no longer necessarily undermines the long-run availability of mineral commodities. Every new baby is born with a brain as well as a mouth. While population growth tends to accelerate the consumption of mineral resources, which pushes costs and prices up, it also increases the human resources needed to generate the new technologies that push costs and prices down over time. This raises the possibility that population growth actually increases the long-run availability of mineral commodities, a possibility that a few scholars suggest is actually the case.[5] It also raises the likelihood that poverty and discrimination (which prevent millions of people from developing their potential and so contributing back to society) may pose a greater challenge than population growth per se. In some countries, of course, population growth may impede development and contribute to poverty.

Fourth, the United States, with three percent of the world's population, consumes 20 to 25 percent of its resources. Similarly, the developed countries with 20 percent of

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[4] See, for example, Barnett and Morse 1963, Krautkraemer 1998, and Howie 2002.
[5] See Simon 1981.

the world's population account for some 80 percent of its resource use. This to many seems unfair to the rest of the world, where billions of poor people struggle daily to survive. Under the opportunity cost paradigm, however, the high levels of mineral consumption in the developed world do not necessarily increase resource scarcity in the rest of the world. While this consumption tends to accelerate mineral depletion, the wealth that it creates in the developed countries supports the technological efforts that push the cost and prices of mineral commodities down over time. It is not an accident that most of the new technologies increasing the availability of many mineral commodities over the past century have come from the United States and other developed countries. This raises the possibility that the poor may actually benefit from the apparent profligate use of mineral resources in the developed world, in the sense that today they have access to cheaper mineral commodities as a result than the developed countries did at comparable stages of development.

So how we look at depletion matters. With the fixed stock paradigm, physical depletion is inevitable. It will come suddenly, and likely take us by surprise. Mineral consumption accelerates the day of reckoning. Both population growth and the widespread use of mineral commodities in the developed world undermine the long-run availability of mineral commodities. Since none of the above is necessarily true under the opportunity cost paradigm, it is fortunate that the latter perspective on mineral depletion is the more appropriate and useful.

Despite the shortcomings of the fixed stock paradigm, however, its simple intuitive logic continues to attract adherents to its way of looking at the depletion issue. This, then, is the first of the three reasons why the debate between the pessimists and optimists remains polarized, even though many mineral commodities according to their trends in real prices have actually become more available over the past century.

Future Trends in Mineral Supply and Demand

Even among those who adopt the more appropriate opportunity cost paradigm, it is important to point out, there is not a consensus regarding the future availability of mineral resources. This brings us to the second reason why the debate continues: Expectations vary greatly regarding future developments in mineral supply and demand.

The cumulative supply curve provides a convenient way of analyzing the numerous supply and demand factors that will determine the future course of mineral prices. This curve, which Figure 1 illustrates, shows how the total supply of oil, copper, or any other mineral commodity varies *over all time* with its price. As the price of copper, for example, rises from 50 cents a pound to 5 dollars a pound, poorer quality deposits can be profitably exploited, and the total amount of copper we can economically mine from the earth's crust increases. So the curve should rise monotonically with price, as shown in Figure 1.

The cumulative supply curve, it should be noted, differs from the traditional supply curve found in every introductory economics textbook. The latter shows how supply *over a given period*, such as a month or year, varies with price. In this case, supply is a flow variable that can continue indefinitely from one period to the next. Cumulative supply, on the other hand, is a stock variable, in the sense that it shows how much of a mineral commodity is economically available over all time at various prices.

The concept of cumulative supply makes sense only for nonrenewable resources. For wheat or fish, for example, there is no reason why supply cannot continue indefinitely into the future as long as production during any particular period does not exceed the level that allows the resource to replenish itself.[6]

The cumulative supply curve, like the traditional supply curve, assumes that all the determinants of supply other than price remain fixed at current or given levels. Exploration, new discoveries, and the development of new mines can take place, but technology, including exploration technology, is assumed to remain unchanged.

The many factors influencing long-run trends in mineral commodity prices fall into three groups. The first includes the incidence and nature of mineral deposits along with other geologic considerations, and determines the shape of the cumulative supply curve. The second group contains those variables that determine the demand over time for mineral commodities, such as the level and growth of population, trends in per capita income, and changes in consumer preferences. These variables affect the speed at which society moves up the cumulative supply curve. The third group contains those variables that cause the cumulative supply curve to shift over time. Changes in wage rates and other input costs belong to this group, but over the long run technological change, which pushes the curve down, is by far the most important of these factors.

The first two groups control the cost-increasing effects of depletion, the last the cost-reducing effects of new technology. The availability of mineral commodities, as a result, will increase over the long run if the tendency for mineral prices to rise as society

[6] For more on the cumulative supply curve, see Tilton and Skinner 1987 and Tilton 2002.

moves up the curve is more than offset by downward shifts in the curve. Why do the optimists believe this will happen? Why are the pessimists skeptical?

Though well aware that past trends need not continue indefinitely, the optimists note that technological change has been for some time successful in offsetting the cost-increasing effects of mineral depletion. Moreover, the success has occurred over a century (the 20th century) when mineral resource use exploded as a result of population growth and rising per capita incomes in the developed countries.

They point out that population growth is slowing. As a result, demographers now believe that the world's population, now at six billion, could peak at about ten billion, and by as early as the end of this century.[7] They also highlight the tendency for the intensity of energy and material use (that is, the quantity used per real million dollars of GDP) to decline over time, which should offset at least in part some of the anticipated effects on mineral demand of growth in per capita income.

They stress the robustness of the marketplace. Any tendency for depletion to drive the price of a mineral commodity up unleashes a number of powerful forces that mitigate any tendency toward growing scarcity. Higher prices encourage exploration for new deposits, the development of new sources of supply, substitution toward more abundant resources, greater recycling, and conservation. More importantly, higher prices increase the expected returns to new technologies that reduce production costs, perhaps by exploiting completely new sources of supply, and to new technologies that reduce consumption.

[7] See, for example, U.S. Census Bureau 2003 and United Nations 2003.

The pessimists have far less confidence in the marketplace and new technology, and believe it is irresponsible to assume that new technology will forever offset the cost-increasing effects of mineral depletion. In the shorter run, they worry about a 50 percent increase in world population over the next half century, and surging mineral demand in China and other parts of the developed world.

Whether the optimists or pessimists are right will likely depend on the shape of the cumulative supply curve. The curve shown in Figure 1a suggests that as cumulative production proceeds over time, the price needed to elicit additional supply increases but at a decreasing rate. If this is the true shape of the curve, then new technology should find it increasingly easy to offset the cost-increasing effects of depletion, lending support to the optimists. However, geologists, relying on the Skinner thesis, point out that the true cumulative supply curve many be far less benevolent than the one shown in Figure 1a.

A geologist at Yale University, Brian Skinner has studied the geochemical formation of mineral deposits. He argues that the cumulative supply curve for copper, lead, tin, zinc, and many other metals could over certain segments have sharply rising slopes or even discontinuities, as shown in Figure 1b and Figure 1c.[8]

This is in part because the geochemical processes that created the mineral deposits for these metals millions of years ago are unlikely to have produced a unimodal relationship between the grade and quantity of metal, such as that shown in Figure 2a. Rather he believes this relationship possesses two or more peaks, as shown in Figure 2b.

[8] See Skinner 1976, Skinner 2001, and Gordon and others 1987.

This means that once the rich (high grade) deposits are exploited, society may have to turn to much lower grade, and so much more costly, deposits for additional supplies.

In addition, the processing methods required to liberate the copper and other metals in very low grade deposits are likely to be quite different from those used today with the high grade deposits. In particular, the use of mechanical and chemical processes for concentrating the ore may not be possible. As a result, the energy required could be one or two orders of magnitude greater, causing a sharp jump in costs. Skinner uses copper to illustrate this possibility. Figure 3 shows how energy requirements could increase if the world had to extract copper from low grade silicate ores rather than high grade sulfide ores.

As Skinner himself points out, his thesis is largely based on theoretical analysis. Very little empirical work has been carried out on processing very low grade deposits, largely because the latter are currently of no commercial interest. This is unfortunate. It means that sharp jumps and discontinuities in the cumulative supply curve are possible, but not certain. In addition, if they do occur, we have little or no idea just how large they in fact will be, nor when they are likely to occur. Given such uncertainty, we simply do not know whether mineral commodities 200 hundred years hence will be more or less expensive, more or less available. This, then, is the second reason why the debate continues. Let us turn next to the third reason, the disparate estimates of the social costs associated with the production and use of mineral commodities.

Environmental and Social Costs

As noted earlier, the focus of the debate has shifted over the past decade or two. Many pessimists are now less concerned about the long-run availability of mineral resources than about the environmental and other social costs associated with their production and use. So, even if the availability of mineral commodities continues to increase in the future, they believe that society may well preclude or restrict their use due to the damage that their production and use inflicts on indigenous cultures, biodiversity, pristine wilderness, and other social goods.

This potential problem arises because the full social costs of producing and using mineral commodities are only partially internalized, that is, paid for by producers and ultimately the consumers of the goods they produce. When a smelter spews sulfur dioxide and arsenic emissions into the air, some of the costs of producing copper are borne by people living downwind. Producers and consumers do not pay for these external costs.

External costs create a number of problems. They in effect mean that society is subsidizing goods with external costs, and so their production is greater than optimal. Second, when some resources, such as clean water or clean air, are free to firms, they tend to overuse these resources in order to conserve on the capital, labor, and other resources for which they have to pay. Third, when resources are underpriced or free, there is little or no incentive to develop new technologies that reduce the need for these resources.

Indeed, the rising environmental costs that the pessimists claim are associated with mineral commodities may largely or entirely reflect this lack of incentive to develop new environmental-saving technologies. Where firms and consumers pay, we have seen that new technology has managed over the long run to offset the cost-increasing effects of depletion. Internalize the environmental and other external costs, the optimists contend, and new technology will reduce these costs just as technology has in the past reduced the capital, labor, and other costs for which producers and consumers have traditionally paid.

While there is much to recommend this proposal, its successful implementation requires three conditions. First, we have to be able to measure the external costs with reasonable accuracy. Otherwise, we do not know how much more producers should be charged. For many environmental goods, this turns out to be a very difficult problem.

This is particularly so for those social goods we prize for their non-use value. For example, many people may place a positive value on maintaining the pristine wilderness of the Amazon region or the slopes of northern Alaska, even though they never plan to visit these areas. Similarly, a sense of fairness and equity may mean that many value preserving the culture and lands of the aboriginal peoples of Australia, even though they are not part of this culture and may not directly benefit from its preservation. The values people attach to such social goods vary greatly, and we have no operating markets where these goods are bought and sold to turn for guidance.

Over the past several decades efforts to value such social goods have relied on either imperfect political processes (similar in ways to the processes that society uses to determine how much to spend on more traditional social goods such as elementary education or defense) or on contingent valuation techniques. The latter rely on sampling procedures that ask people what they would be willing to pay to preserve pristine wilderness or other social goods. However, respondents do not actually have to pay, and for this and other reasons, these techniques remain quite controversial. So despite considerable progress in this area over the past several decades, much more is needed before we can reliably measure the value of many social goods.[9]

Once the external costs are measured, governments must have the means and the will to force the firms responsible to pay for them. This second necessary condition is much less of an issue. For most countries, the government does possess the means. Indeed, the current debate in this area is largely over which set of means to use: command and control regulations that stipulate how firms should behave, including the technologies they must use; or taxation and other economic incentives that encourage firms to meet certain goals, but leave them more freedom to achieve the goals in the most cost-efficient manner.

In most instances, governments also possess the will to internalize all the social costs, though problems can arise when the external costs are global in nature, as for example in the case of global warming. In such instances, many governments would prefer to have firms in the rest of the world cover most or all of the external costs. Artisanal mining is another example of where the lack of will can be a problem. In many ways, artisanal mining is mining at its worst. Small scale and largely unmechanized, it tends to be highly inefficient. It is also dangerous, and per unit of output extremely damaging to the environment. Many developing countries around the world, however, hesitate to force these producers to pay their full social costs. Doing so would force most to close, and remove one of the few economic opportunities available to poor people living at the margin of subsidence.

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[9] Carson and others 2001 provides a recent review of the debate over contingent valuation, and argues that most of the shortcomings can be overcome.

Finally, once the external costs are measured and internalized, new technology must be up to the challenge of reducing these costs over time. Whether this will actually be the case or not is uncertain, though anecdotal evidence suggests that this last necessary condition may be the least problematic of the three. Over the past several decades governments around the world have increased the stringency of their environmental regulations. In many instances, this has led to the introduction of new technologies and the sharp reduction in the environmental costs associated with mineral commodities.

For example, forty years ago copper smelters released most or all of their sulfur dioxide emissions into the air. Today, most capture 80 percent or more of this pollutant, and modern smelters in Japan and elsewhere are recovering 98 percent or more. In addition, over this period, a growing share of the world's copper has been produced by a new technology, solvent extraction electrowinning, which completely bypasses the smelting stage and emits no sulfur dioxide emissions.

Countless other examples could be cited, demonstrating the power of new technologies to reduce the environmental costs of mineral commodities once the internalization of these costs produces the incentives to develop such technologies. While such evidence does not of course prove that new technology can forever reduce the environmental costs associated with mineral commodities, it does suggest that new technology can be just as effective in reducing environmental costs as the labor, capital, and other, traditionally internalized, costs of mineral products.

Many pessimists, however, place a very high value on indigenous cultures, biodiversity, pristine wilderness, and other social goods that mineral production and use can threaten. In their view, the external costs remain very high, indeed perhaps many multiples of the currently internalized costs, despite recent efforts by governments to internalize more of these costs. In this case, the internalization of all costs may encourage new technologies that reduce the previously external costs, but the costs that producers and consumers actually pay would likely rise, and possibly quite substantially. This could, as the pessimists predict, curb the use of mineral commodities in the future. However, this pessimistic scenario assumes that the true external costs are very high. While such assessment may accurately reflect the values of particular individuals, the extent to which they can be generalized and thus used to represent the values of society collectively is uncertain.

So unraveling the third reason why the debate between the optimists and the pessimists continues—the issue of full environmental and social costs—awaits the development of more widely accepted methods for estimating the full social costs associated with mining and mineral commodities. Of the three needed conditions to resolve this issue, this remains the most challenging.

Long-Run Availability

The debate over the long-run availability of mineral commodities, as discussed above, continues largely for three reasons—the use of different paradigms, the uncertainties regarding future developments in mineral supply and demand (and especially the unknown shape of the cumulative supply curve), and the lack of widely accepted methods for assessing the full social costs of producing and using mineral products.

As the opportunity cost paradigm for several reasons provides a more appropriate and useful way of assessing the threat of mineral depletion than the fixed stock paradigm, we can with some confidence resolve the first of these three issues. The uncertainties associated with future developments in mineral supply and demand and those associated with full cost pricing, however, pose much more troubling hurdles for reliable long-run forecasts.

If the slope of the cumulative supply curve rises gradually and at a decreasing rate, then new technology should have little trouble offsetting the cost-increasing effects of depletion over time. Conversely, if segments of the curve turn dramatically upward or incur discontinuities, future trends in resource availability could prove quite troubling. More geologic information on subeconomic mineral deposits would likely provide useful insights into the shape of the cumulative supply curve. At the present time, empirical evidence on the nature and incidence of subeconomic deposits is woefully lacking, making it difficult to confirm or refute the Skinner thesis. Without such information, forecasting long-run trends in real mineral commodity prices with any accuracy is simply not possible.

Added to this problem are the uncertainties surrounding full cost pricing. While there is widespread agreement that the prices of mineral commodities should reflect their full social costs, including any currently external costs, there is considerable disagreement over the actual magnitude of the external costs and how to appraise them. This is troubling for two reasons. First, public policy cannot internalize external costs if they cannot be measured. And, as long as producers do not pay for the environmental and other social costs associated with mineral commodities, they will have little incentive to develop new technologies to reduce these costs. This robs society of its most effective weapon for keeping the cost-increasing effects of depletion at bay.

Second, without a reliable method for measuring external costs, a wide range of opinions—from quite modest to many multiples of the current internalized costs—must be considered seriously. If the external costs are in fact quite large, mineral commodity prices could be much higher once firms and consumers are forced to pay them. This could limit the future use of mineral commodities significantly.

Unfortunately, the more widely-used methods for assessing external costs provide highly variable estimates. Contingent valuation studies are known for their sensitivity to the procedures adopted and the assumptions made. The political process also provides mixed signals. Some countries, such as Chile, make it easy for companies to develop new mines. Presumably these states believe that the environmental and other social costs associated with mining are modest compared to the benefits for the country. In California, Wisconsin, and British Columbia, however, it is far more difficult to get the necessary permits for new mines. Their collective assessment of the associated external costs presumably is far higher. Fifty years ago society paid little attention to the external costs associated with mineral commodities. While this is clearly no longer the case, we simply do not know whether the assessment and policies of California, Wisconsin, and British Columbia are peculiar and passing anomalies, or whether they are the wave of the future.

What are the implications of such uncertainties, both for the long-run availability of mineral commodities and for the on-going debate over this issue? It is clear that neither the optimists nor the pessimists currently have the needed evidence to prove the other side wrong. So perhaps the only reliable prediction one can make is that the debate will continue. Claims that mineral depletion unquestionably does, or does not, pose a serious threat to the welfare of modern civilization should be treated with some skepticism.

On this last point, let me end with a quote from *On Borrowed Time?* (Tilton, 2002, pp. 118-9):

> So are we living on borrowed time? Is modern civilization as we know it threatened by the depletion of oil and other mineral commodities? Are drastic public policies needed to avert disaster and to provide a secure future for generations to come? Are public policies needed simply as a precaution or as insurance against the possibility that depletion may be a problem in the future?
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> Modern-day prophets cry out yes, and yes again, to all of these questions. They call upon society to repent and to mend its ways. To curb its population growth. To restrain its use of mineral resources. To tame its passion for more and better things. To turn away from materialism, and to embrace a simpler life.
>
> Standing at the other end of the spectrum are the prophet slayers. They claim the availability of mineral resources poses no problems, now and forevermore (or at least for as long as we might have an interest in the future). They contend our prophets are not prophets at all, but Chicken Littles running about crying the sky is falling.
>
> The public is fascinated with its prophets and prophet slayers. They come with clear and uncomplicated messages, painting the world in black and white. They tell us what we need to know, what we need to think, and what we should or should not do. They are colorful, passionate, and so convinced they are right that it is hard to resist being swept up in their enthusiasm.
>
> The real world, however, is not so simple. Rarely is it painted in black and white. Rather it is bedecked in hues of gray, and a palette of bright colors. It is full of risks, uncertainties, unknowns, and complications—all traits that make life interesting, exciting, and challenging, even if at times frustrating and troubling as well.
>
> And so it is with our fears of mineral depletion. Over the next 50 to 100 years, . . . mineral depletion is not likely to rank among the most pressing problems confronting society. The great beyond, however, depends on the race between the cost-increasing effects of depletion and the cost-reducing effects of new technology. The outcome will be influenced by many factors, and is simply unknown.

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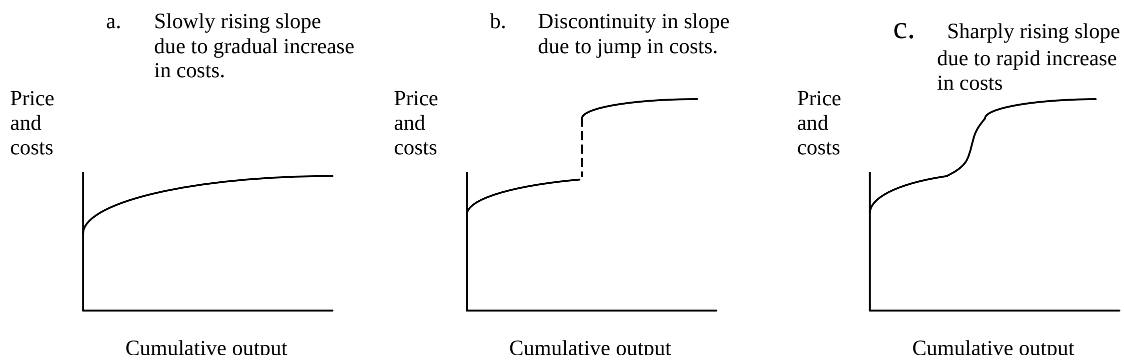
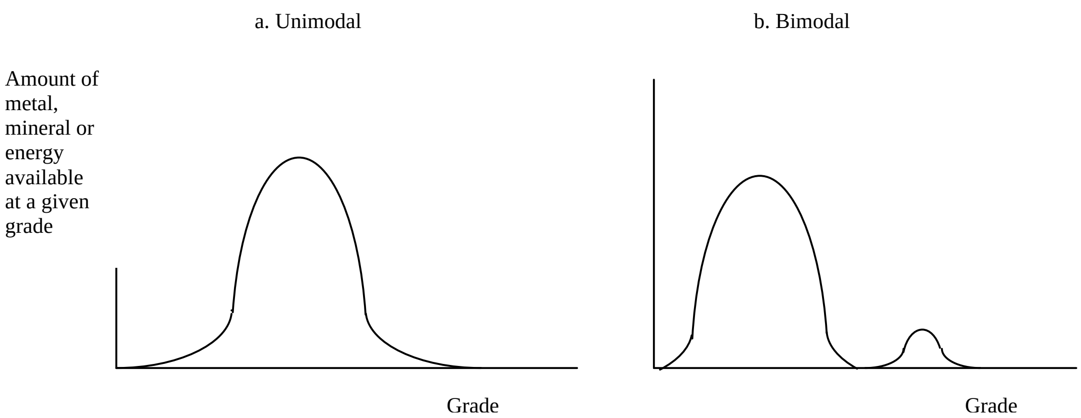
Figure 1. Illustrative Cumulative Supply Curves



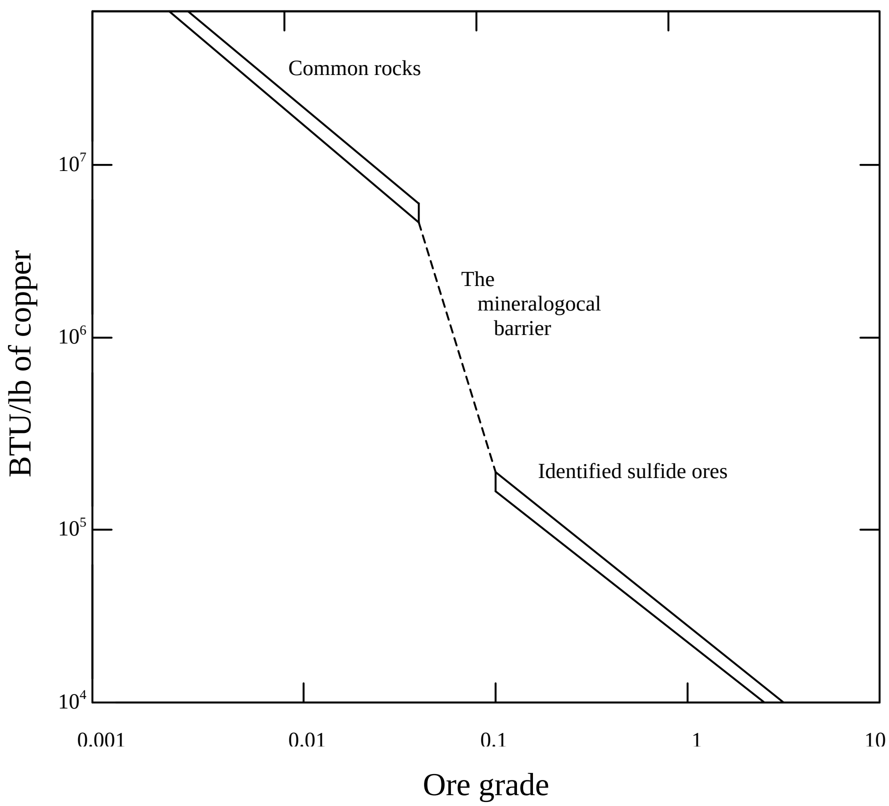
Source: Tilton and Skinner (1987).

Figure 2. Two Possible Relationships Between Ore Grade and the Metal, Mineral, or Energy Content of the Resource Base



Source: Skinner (1976).

Figure 3. Energy Required per Pound of Copper From Sulfide Ore and Common Silicate Rock



Source: Skinner (1976)