Chapter 3

IMPERFECT MEASURES

There are many ways to measure resource availability. While none are perfect, some are better than others. This chapter first considers measures that are entirely or largely physical in nature. These measures are frequently encountered in the literature and have considerable intuitive appeal. It then reviews measures that are economic in nature. While all the economic measures have shortcomings, we will see that they are more useful than physical measures for assessing the long-run threat from mineral depletion. In Chapter 4, as a result, we rely on economic measures to identify the historical trends in mineral commodity availability.

Physical Measures

The logic behind physical measures is both simple and appealing. As Chapter 1 notes, since the earth is finite, it contains a fixed amount of oil, coal, iron, copper, and any other particular substance. Consequently, the supply of all mineral commodities is a fixed stock. Physical measures attempt to assess the remaining stock at any point. The demand for mineral commodities, on the other hand, is a flow variable that continues year after year. So eventually demand must consume the available supply, causing the physical exhaustion of the commodity. To assess how long the available stock will last—the life expectancy of the commodity—one has only to forecast trends in its future use.

This view of the depletion process, in large part because it is so logical, is frequently encountered. Over the years, as we saw in Chapter 2, it has greatly influenced the literature, from Malthus to the Conservation Movement to Hotelling (as well as many of the economists who have followed in Hotelling's footsteps by extending on the theory of exhaustible resources).

Reserves

Though the logic behind physical measures is simple, estimating the remaining available stock of a mineral commodity raises some difficult issues. The most common approach is to use reserves (or measures closely related to reserves). By definition, reserves are the quantities of a mineral commodity, such as oil or copper, found in subsurface resources (fields, deposits) that are both known and profitable to exploit with existing technology and prices.

Data on reserves for individual countries and the world as a whole are readily available from the U.S. Geological Survey, from similar government agencies in other countries, and from international organizations. Column 2 of Table 3.1 shows the world reserves in 1999 for a sample of mineral commodities. By themselves, they are not particularly enlightening, and normally one uses such data to calculate mineral commodity life expectancies. This, however, requires forecasts of future demand along with estimates of how much of the future production will come from primary production and mining, and how much will come from secondary production and recycling. It is only primary production, of course, that depletes reserves.

Table 3.1 deals with this issue by showing life expectancies assuming primary production will grow at annual rates of zero, two, and five percent. The average rate of growth in primary production over the past 25 years for each mineral commodity is also shown in Table 3.1. In most cases, this average growth rate falls between zero and five percent. Lead and tin are the exceptions. Their growth has averaged a negative 0.5 percent annually.

Not surprisingly life expectancies vary greatly. The faster future demand and primary production are expected to grow, the lower they are, often by many years. For a few mineral commodities, such as magnesium (recovered from sea water) and potash, which are not shown in Table 3.1, reserves are sufficient to last for millennia at current rates of production. For most, however, the results are more disturbing, suggesting that many mineral commodities will be gone within a century or in a few cases even within a couple of decades.

This pessimistic scenario, however, presumes that reserves reflect the fixed stock of mineral commodities remaining to be exploited. This simply is not so. Reserves indicate the amount of a mineral commodity found in deposits that are known and profitable to extract with current technology and prices. While extraction over time is depleting reserves, the discovery of new deposits by exploration and the conversion of known but uneconomic resources into profitable deposits by new technology, both add to reserves. Indeed, even in a static world with no exploration or new technology, reserves can increase as a result of rising mineral commodity prices or declining costs of labor, capital, and the other factors of production employed by the mineral industries.

Since exploration, new technology, and the other factors do increase reserves over time, reserves should not be thought of as long-run indicators of mineral availability, but rather as working inventories that energy and mineral companies can increase by investing in exploration and new technology. In many mineral industries, once reserves reach 20 to 30 years of current production, companies have little incentive to invest in developing their reserves further.

Some studies attempt to overcome the inherent problems of using reserves to measure mineral availability by increasing reserves in an arbitrary manner. *Limits to Growth* (Meadows and others 1972), for example, employs a multiple of reserves in its simulation efforts. Others use the concept of resources, rather than reserves, where resources include reserves plus the quantity of a mineral commodity contained in deposits that are either expected to be found or to become economic as a result of new technology or other developments within some foreseeable future. All these attempts, however, suffer from the same fundamental problem as reserves; namely, the resulting figures are ultimately not fixed stocks reflecting the remaining availability of mineral commodities.

Resource Base

An alternative physical measure that comes much closer to measuring the total amount of various mineral commodities found in the earth is the resource base. This measure encompasses all of a mineral commodity contained in the earth's crust. It includes reserves, resources, as well as the contents of all other subsurface occurrences, whether or not they are known or likely soon to become so, and whether or not they are currently economic to exploit or likely soon to become so. The relationship between reserves, resources, and the resource base is shown in Figure 3.1, a modification of the well-known McKelvey box.

Table 3.2 shows the resource base for a number of mineral commodities, along with their life expectances assuming the demand for primary production grows at zero, two, and five percent annually. The most striking finding is the sheer magnitude of the figures. At current rates of primary exploitation, all the mineral commodities for which we have resource base estimates would last for millions of years, some for billions of years! Given that our solar system is only about five billion years old and that homo sapiens have existed as a species for only several hundred thousand years, these are large numbers. They suggest that society might have more pressing problems than mineral depletion.

However, Table 3.2 also shows that assuming a continuous growth in primary production of only two percent annually reduces the life expectancies of the resource base from millions and billions to hundreds and thousands of years. While these figures are small enough to perhaps cause some concern, they like the larger figures are not very useful indicators of the long-run availability of mineral resources for several reasons.

First, many mineral commodities are not destroyed after they are extracted and used. Ignoring the trivial amounts that have been shot into space, the world today has as much copper, lead, and zinc as it ever has had. Some past production of these metals has been degraded and discarded. Recovering and reprocessing this material may be expensive, but this is a issue of costs, not of physical availability.

Second, while recycling is not an option for the energy resources, their ultimate scarcity is constrained by substitution opportunities and backstop alternatives. Coal, natural gas, petroleum, hydropower, uranium, wind, and solar power, for example, can all produce electricity. The mix of these resources used at any particular time depends largely on their relative costs.

Of course, certain energy resources, such as petroleum, have unique characteristics that at the present time make substitution difficult or impossible in some applications. The automobile with its internal combustion engine, for instance, depends on petroleum as it requires a mobile energy source. However, the opportunities for resource substitution are growing in many important end-use energy applications. Nowhere is this more evident than with the automobile, where new technology is rapidly advancing the prospects for using electricity, fuel cells, and other alternative fuels to power the car of the future. Such alternatives are now technically feasible; their widespread adoption is largely a question of costs.

In light of such substitution opportunities, the depletion of a particular resource poses a problem only if all the alternatives are similarly suffering from growing scarcity. While the resource base for many of the nonrenewable energy minerals is unknown (and may be smaller or larger than often assumed), the availability of renewable energy resources, particularly solar power, is for all practical purposes unlimited.[1]

[1] The availability of solar power reaching the earth's upper atmosphere equals the solar constant times the area of the earth presented to the sun. The solar constant (SC) is the rate of arrival of energy per unit area perpendicular to the sun's rays at earth's location. This equals 1350 watts per square meter (Giancoli 1997). The area of the earth presented to the sun equals $\prod R^2$, where R is the radius of the earth (6.38×10^6 meters) and $\prod$ is the well-known ratio of the circumference of a circle to its diameter (3.14159). So the solar power reaching the upper atmosphere is $SC \prod R^2 = 1350 \times 3.14159 \times (6.38 \times 10^6)^2 = 1.73 \times 10^{17}$ watts. Since only about 50 percent of this energy reaches the ground (Ristinen and Kraushaar 1998), the total solar power reaching the earth's surface is half of this figure, or 9×10^{16} watts. Multiplying this figure by

Third, the resource base ignores the possibility of extracting mineral commodities from beneath the earth's crust or from space. While such activities seem far-fetched at the present time, there are on-going discussions of mining on the moon and on near-earth asteroids. History suggests that many activities that seem implausible today may be commonplace in a century or two.

Fourth, and perhaps most important, before the world extracts the last drop of oil or the last molecule of silver from the earth's crust, rising costs would completely eradicate demand. This means that economic depletion would threaten the availability of resources long before the physical exhaustion of the resource base would occur.

For these reasons, costs and prices, properly adjusted for inflation, provide a better early warning system for long-run resource scarcity than the available physical measures. This brings us to the economic measure of availability.

Economic Measures

the number of hours in a year (24 x 365) and then dividing by 1000 (to convert from watts to kilowatts) indicates that 79×10^{16} kilowatt-hours of solar energy reach the earth's surface annually.

To comprehend the magnitude of this figure, we can compare it to the energy derived annually from global petroleum production. The amount of energy in a barrel of oil varies. For the United States it averages about 5.8 million Btu's (U.S. Energy Information Administration, 2001a), or the equivalent of 1.7 thousand kilowatt-hours. As shown in Table 3.1, annual global crude oil production averaged 23.7×10^9 barrels over the 1997-1999 period. At 1.7 thousand kilowatt-hours per barrel, this output contains 4×10^{13} kilowatt-hours of energy, or approximately 0.005 percent of the solar power reaching the earth's surface every year.

According to the U.S. Energy Information Administration (2001b), crude oil production accounts for 40 percent of global energy output. So total energy output currently equals 0.012 percent of the available solar power. This means that the physical availability of solar power is some 8,000 times greater than current energy production. The point is not to suggest that some day the world may use all of its available solar power. The costs, including the environmental costs, of solar power presumably would rise sufficiently to make the additional use of solar power uneconomic long before the world was completely covered with solar panels. The point rather is simply that it is costs, and not physical availability, that ultimately determines the availability of energy commodities.

There are three widely recognized economic measures of the long-run availability of mineral commodities—the marginal costs of extraction and processing, the market price of the mineral commodity, and user costs. As pointed out in Chapter 2 (see Figure 2.1), mineral commodity producers have an incentive to expand output up to the point where marginal production costs plus user costs just equal the market price. So these three economic measures are related.

Figure 3.2 illustrates the nature of this relationship. The vertical axis shows the market price for a mineral commodity, and the production costs for the various (discovered) deposits from which mineral companies can produce the commodity. Production costs differ because deposits vary in quality. Some are high grade, easy to process, and located close to cheap ocean transportation with needed infrastructure already in place. Others are not. The column marked A in Figure 3.2 identifies the lowest cost (highest quality) deposit. It can produce an output of OA annually at a per unit cost of OC_1. Column B indicates that the next best deposit can produce AB a year at a per unit cost of OC_2. Column C represents the third best deposit, and so on.

The figure indicates that the market price is P and user costs are C_mP per unit of output. It also assumes that per unit production costs vary little within any given ore body or deposit, at least compared to the differences in costs between deposits. For this reason, production costs are portrayed as a horizontal line for each deposit.

Assuming that mining companies develop and mine deposits if, and only if, the market price covers their production costs plus user costs, a long-run industry supply curve can be constructed by adding user costs (C_mP) to the height of each column (the production costs) in Figure 3.2. At the market price P, the industry will produce the output OM from the first M deposits. The ores contained in these deposits are reserves. Columns N and higher represent deposits that are not profitable to exploit at the price P. The minerals they contain are resources but not currently reserves.

The production costs plus user costs for deposit M are just equal to the market price, and it is this deposit that illustrates the relationship between market price, marginal production costs, and user costs—our three economic measures of resource availability. Intra-marginal deposits, those in categories A through L, enjoy production costs plus user costs that are lower than the market price, and so they earn an additional profit as a result of their superior quality. This extra profit, as noted in Chapter 2, is commonly called Ricardian rent. As Figure 3.2 shows, while only deposits A through L enjoy Ricardian rents, they as well as deposit M earn user costs.

While Figure 3.2 highlights the relationship between price, costs, and user costs, these three indicators of resource availability measure different things. The market price reflects the opportunity cost (in the sense of what has to be given up) of obtaining another unit of the mineral commodity—a barrel of crude oil or a ton of refined copper, for example.

User costs reflect the opportunity cost or the value of the oil or copper ore in the ground. Under certain conditions, user costs approximate the additional costs of finding one more unit of marginal quality (category M) reserves.[2] Higher quality reserves normally are more costly to discover.

Extraction and processing costs reflect the value of the labor and other inputs required to extract resources from the ground and to convert them into crude oil, refined

[2] This follows when firms have an incentive to expand their exploration efforts up to the point where the cost of finding another unit of reserves just equals the value of that unit.

copper, or other mineral commodities ready to be sold in the marketplace. These differences mean that the three economic measures may provide different signals regarding the long-run availability of mineral commodities.

In a static world where no discovery or new technology occurs and where the existing ore is all of the same quality, Hotelling (1931) has shown that user costs rise at r percent a year (the rate of return on other assets similar to mineral resources in the ground). Extraction and processing costs remain constant. As a result, the marginal cost of producing the last unit of output is the same for each period, and equals the average costs across all output. In this situation, the market price rises at the same absolute rate as the user costs. Unless extraction and processing costs are zero, however, the percent increase in the market price is less than r percent, the rate for user costs. In this situation, user costs and to a lesser extent market prices indicate growing scarcity, while production costs show no change in resource availability.

Allowing for technological change in the extraction and processing of mineral commodities introduces the possibility that production costs may decline over time. Such a decline may more than offset the rise in user costs, allowing the market price to decline. This favorable trend may not continue indefinitely, however, as over time user costs account for a growing portion of the market price. As Chapter 4 points out, this possibility has led Slade (1982) and others to hypothesize that real mineral commodity prices follow a U-shape curve over time, first declining and then rising.

Going one step further, and allowing not only for technological change in extraction and processing but also for new discoveries and mineral deposits of varying qualities, introduces the possibility that user costs as well as production costs may fall over time, permitting market price to decline indefinitely. To illustrate this possibility, consider Figure 3.2 once again and assume that there are many large deposits with the same production costs as deposit N. In this case, production costs, once they reached those of deposit N, would stabilize. User costs would decline, as the lost future profits associated with increased output today would not arise for many years, not until deposit N and all other similar deposits were exhausted. The present value of these lost profits as a result would likely be far lower than the present value of the lost future profits associated with increasing current production prior to the exploitation of deposit N.

Such situations may arise where backstop technologies exist. Should the cost of producing natural gas, for example, rise sufficiently so that solar energy becomes economic, the user costs associated with energy production from natural gas would fall to zero.

Challenges to Economic Measures

Our economic measures (price, marginal production costs, and user costs) of mineral resource availability, though now generally accepted as superior to the physical measures (reserves, resources, and the resource base), are not perfect. Mineral commodity prices, for example, may at least in the short run be more influenced by cyclical fluctuations in the business cycle, accidents, strikes, and other factors than trends in long-run availability. They can also be distorted by a variety of market imperfections, including cartels and other forms of market power, government price controls, public subsidies, and environmental and other social costs that producers and consumers do not pay. The sharp rise in oil prices in the early 1970s, for example, reflected more the market power of OPEC and short-run fluctuations in the business cycle than rising long-run availability problems.

Similarly, market imperfections and short-run disturbances, again particularly in the short run, may distort extraction costs on the margin. The jump in oil prices in the early 1970s, for example, stimulated investors to develop high-cost wells that previously were uneconomic. An additional shortcoming of extraction costs is their failure to anticipate the future. While current mineral commodity prices will rise in anticipation of future shortages, extraction costs depend on the quality of the resources currently being used rather than the quality of those the future will use.

User costs are particularly easy to interpret when extraction costs are constant. When extraction costs are rising, however, we have seen that user costs can decline as society moves to poorer quality but more abundant resources. This reflects a reduction in the future threat of resource shortages, but does not reflect past trends very well. If extraction costs focus too much on the past, user costs suffer from the opposite problem.

Another shortcoming of our economic measures of scarcity is that they can provide quite different indications of resource availability trends. New technology, for example, may over time drive production costs down while depletion may be pushing user costs up. Mineral commodity prices in such situations may be rising, falling, or constant, and the implications for trends in mineral commodity availability are ambiguous.

Ecological economists and others also challenge the use of our economic indicators on the grounds that they are mere reflections of a fundamentally flawed market process. Here the case against economic measures encompasses several concerns.

First, the economic system, it is argued, is just a part or a subsystem of a finite global ecosystem. The economic system extracts resources from and jettisons waste back into the ecosystem. While the world economy was small, the ecosystem absorbed these interactions with little or no costs. With the growth in the global economic system over the past century, however, this has changed, and as a result large environmental and social costs associated with current economic activities are not reflected in the costs that producers incur or the prices that consumers pay. In a debate with Julian Simon, Norman Myers (Myers and Simon 1994, p. 185) advanced this view:

> The goods we purchase have often been produced at a concealed cost of pollution during the production process, and when we consume them or throw them away after use, still more pollution ensues, for instance, acid rain, ozone-layer depletion, and global warming. This is pollution for everybody today and tomorrow, not just for the purchaser. Yet the social costs are far from reflected in the prices we pay: the economic externalities are rarely internalized, even though they should be if prices are to serve as realistic indicators. Externalities are nothing less than larcenous costs imposed on other people.

Traditional economists would agree that all costs, including the environmental and other social costs, of producing mineral commodities should be internalized if prices and costs are to reflect true trends in resource availability. The critics, however, believe that external costs are very large and pervasive. They question whether society has the ability or the will to force producers and consumers to pay these costs. They also contend that the prices and costs recorded for mineral commodities in the past would be much higher and increasing much faster if these costs were taken into account.

Second, the marketplace provides reliable indicators of scarcity only if participants determining mineral commodity prices, extraction costs, and user costs are themselves properly informed. As Norgaard (1990, pp.19-20) has suggested: "If resource allocators are not informed, the cost and price paths their decisions generate are as likely to reflect their ignorance as reality."

Third, a small percentage of the world's population unduly determines the demand for mineral commodities due to the very skewed distribution of global income and wealth. Again, according to Myers (Myers and Simon 1994, p. 185):

> In any case, market indicators . . . reflect the evaluation only of those people who can register their money votes in the marketplace—an option that, as we have seen, is almost entirely denied to two people out of five worldwide. What would be these people's reaction to . . . assurances that spending power is steadily enhance through declining prices—or that the Waldorf is increasingly open to all?

Distortions in demand bias the trajectories of prices and the other economic indicators of resources availability. A more equitable distribution of income and wealth would allow the bottom third of the world's population to increase greatly their demand for housing, food, and other basic necessities. Of course, the richest third would have to reduce its demand for goods and services, but overall such a transformation would likely increase appreciably the demand for materials and energy. This in turn would generate a different, perhaps very different, pattern of mineral commodity prices and production costs than that produced by the highly inequitable market system that currently exists.

Fourth, the market system also fails to give adequate weight to the interests of future generations, as it is the living alone (and not their yet-to-be-born descendents) who interact in the marketplace and shape the public policies that determine commodity prices. If the voices of future generations were taken into account, the critics claim, we would discount future profits less and raise current commodity prices in order to tilt the consumption of resources more toward the future.

Fifth, the marketplace is anthropocentric and takes into account only the interests of people. Yet other species, it is argued, have intrinsic value as well. The market and public policy consider their interests only to the extent that people are prepared to champion them. This market imperfection again calls into question the validity of the economic measures of resource availability, and raises the possibility that both the level and trends in commodity prices might be far higher if the welfare of all living creatures, rather than just people, were properly considered.

These challenges to the economic measures of resource availability raise important issues, which deserve more attention. The first contends that the true costs of mineral production (and many other economic activities) far exceed the costs that producers incur and in turn the prices consumers pay. This implies a massive failure of public policy to internalize the environmental and other social costs. Few would argue that public policy is perfect. Vested interests and widespread ignorance can and often do promote sub-optimal policies. The issue here, however, is how convincing a case can be made for massive failure over an extended period of time, particularly for those countries where governments are ultimately accountable to their citizens.

The second concern—that the ignorance of market participants cripples our economic measures of resource availability—highlights the complications introduced by uncertainty and imperfect information. To what extent these complications undermine the usefulness of economic measures, however, depends on (a) the use to which they are put and (b) the pervasiveness of the ignorance. If the objective is to forecast accurately on the basis of current indicators, and if one believes that current participants in the marketplace are ill informed, then the economic measures are of questionable use. On the other hand, if current participants are thought to be reasonable savvy, one should have more confidence in the trends portrayed by economic measures. In either case, as Krautkraemer (1998, p. 2008) points out, economic indicators reflect the ". . . available information about scarcity at a particular time and that information changes over time." So economic indicators should reflect the collective wisdom of the market about how resource scarcity is changing. While this collective wisdom is imperfect, the critical question is whether it runs counter to the best evidence available on future resource scarcity over an extended period of time.

The other challenges to the economic measures of resource availability raise even more fundamental philosophical issues, regarding not just how to measure resource availability, but more importantly, the values we hold individually and collectively as a society, and thus consider when allocating resources and making decisions. Ultimately, however, these challenges are relevant only to the extent that they influence those individuals whose decisions and behavior matter, as the following quote from Stokey and Zeckhauser (1978, p. 262) so colorfully argues:

> Our main point is that it's people, and only people, that count. This means that redwoods and bluebirds and Lake Baikal and the Old

> Man of the Mountain are worth saving only if people believe them worth saving. Abstractly considered, the rights of nonhuman entities may seem a valid criterion for policy. But in fact these rights are meaningless unless championed by people; neither the redwoods nor the bluebirds can speak for themselves. If this judgment strikes you as unduly hard-nosed, look at the other side of the coin. How many voices are raised on behalf of that vanishing species, the smallpox virus? And who speaks for the boll weevil? There is ample pragmatic support for an anthropocentric approach. All philosophical justifications to the contrary, unless human beings care about redwoods, the redwoods will be destroyed.

While many thoughtful individuals would like to see a more equitable distribution of global income and wealth, it matters little for resource availability (or anything else for that matter) until such concerns actually affect the purchasing power of the economically disenfranchised. Similarly, the interests of future generations or of other species, regardless of the arguments on their behalf, affect the present only to the extent that the current generation of humans takes them into account. To say trends in resource availability would have been less favorable if public policy had been different (better) may be interesting, but it in no ways alters the actual trends.

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Figure 3.1. Reserves, Resources, and the Resource Base

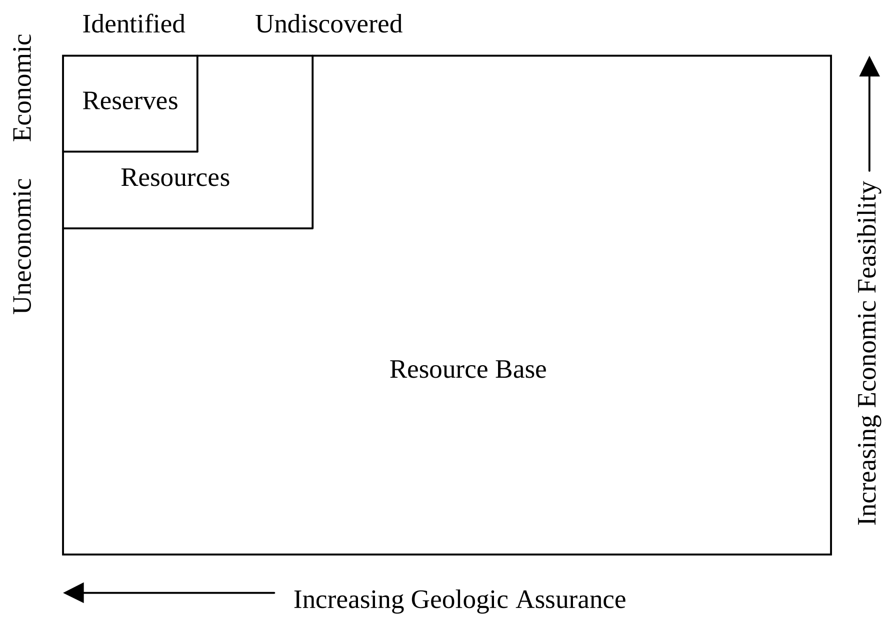

Figure 3.2. Market Price, Production Costs, User Costs, and Ricardian Rents

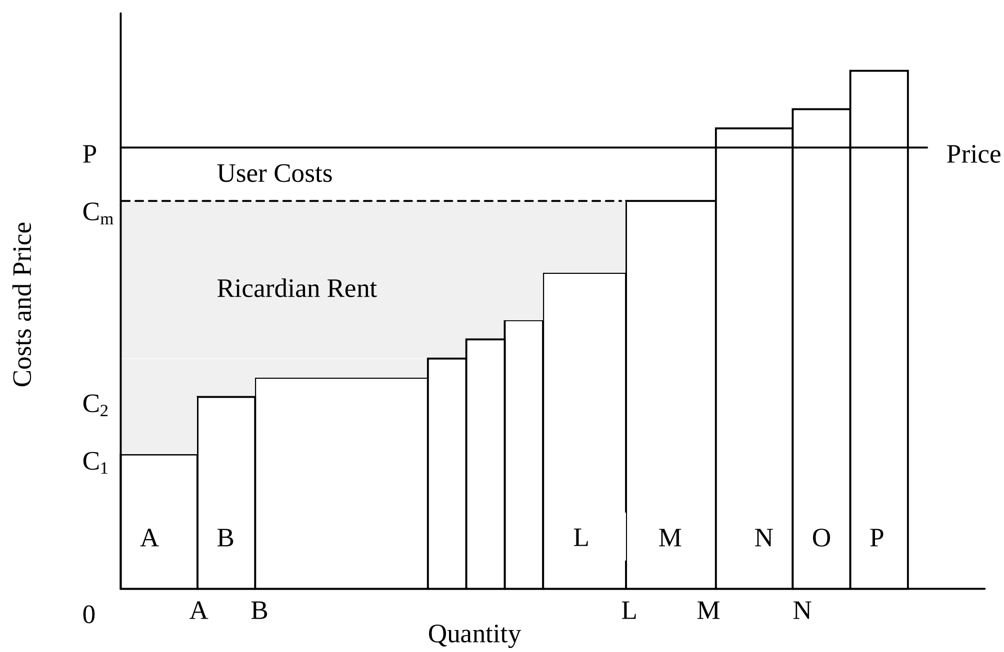

Table 3.1. Life Expectancies of World Reserves, Selected Mineral Commodities

Mineral Commodity[a]	1999 reserves[b]	1997-1999 average annual production[b]	Life expectancy in years, at three growth rates[c]			Average annual growth in production, 1975-1999 (percent)
			0%	2%	5%	
Coal	987×10^{9}	4561.3×10^{6}	216	84	49	1.1
Crude Oil	1035×10^{9}	23.7×10^{9}	44	31	23	0.8
Natural Gas	5145×10^{12}	80.5×10^{12}	64	41	29	2.9
Aluminum	25×10^{9}	123.7×10^{6}	202	81	48	2.9
Copper	340×10^{6}	12.1×10^{6}	28	22	18	3.4
Iron	74×10^{12}	559.5×10^{6}	132	65	41	0.5
Lead	64×10^{6}	3070.0×10^{3}	21	17	14	-0.5
Nickel	46×10^{6}	1133.3×10^{3}	41	30	22	1.6
Silver	280×10^{3}	16.1×10^{3}	17	15	13	3.0
Tin	8×10^{6}	207.7×10^{3}	37	28	21	-0.5
Zinc	190×10^{6}	7753.3×10^{3}	25	20	16	1.9

Sources: U.S. Bureau of Mines (1977), U.S. Geological Survey (2000a); U.S. Geological Survey (2000b); American Petroleum Institute (2000); BP Amoco (2000); International Energy Agency (2000).

Notes:

[a]For the metals other than aluminum, reserves are measured in terms of metal content. For aluminum, reserves are measured in terms of bauxite ore.

[b]Reserves are measured in metric tons except for crude oil, measured in barrels, and natural gas, measured in cubic feet.

[c]Life expectancy figures were calculated before reserve and average production data were rounded.

Table 3.2. Life Expectancies of Resource Base, Selected Mineral Commodities

Mineral Commodity	Resource base[b] (metric tons)	1997-1999 average annual production	Life expectancy in years, at three growth rates			Average annual growth in production, 1975-1999 (percent)
			0%	2%	5%	
Coal[a]	n/a	4561.3×10^{6}	n/a	n/a	n/a	1.1
Crude Oil[a]	n/a	23.7×10^{9}	n/a	n/a	n/a	0.8
Natural Gas[a]	n/a	80.5×10^{12}	n/a	n/a	n/a	2.9
Aluminum	2.0×10^{18}	22.4×10^{6}	89.3×10^{9}	1065	444	2.9
Copper	1.5×10^{15}	12.1×10^{6}	124.3×10^{6}	736	313	3.4
Iron	1.4×10^{18}	559.5×10^{6}	2.5×10^{9}	886	373	0.5
Lead	290.0×10^{12}	3070.0×10^{3}	9.4×10^{6}	607	261	-0.5
Nickel	2.1×10^{12}	1133.3×10^{3}	1.8×10^{6}	526	229	1.6
Silver	1.8×10^{12}	16.1×10^{3}	111.8×10^{6}	731	311	3.0
Tin	40.8×10^{12}	207.7×10^{3}	196.5×10^{6}	759	322	-0.5
Zinc	2.2×10^{15}	7753.3×10^{3}	283.7×10^{6}	778	329	1.9

Sources: The data on the resource base are based on information in Brobst and Pratt (1973, pp. 22-23) and Lee and Yao (1970, pp. 778-86). The figures for the 1997-1999 average annual production and the annual percentage growth in production for 1997-1999 are from Table 3.1 and the sources cited there.

Notes:

[a]Estimates of the resource base for coal, crude oil, and natural gas do not exist. As a result, data for the resource base and life expectancies for these commodities are not available (n/a). The U.S. Geological Survey and other organizations do provide assessments of ultimate recoverable resources for oil, natural gas, and coal. While these are at times referred to as estimates of the resource base, they do not attempt to measure all the coal, oil, and natural gas found in the earth's crust. As a result, they are more appropriately considered as resource estimates, rather than assessments of the resource base.

[b]The resource base for a mineral commodity is calculated by multiplying its elemental abundance measured in grams per metric ton times the total weight (24×10^{18}) in metric tons of the earth's crust. It reflects the quantity of that material found in the earth's crust.