Chapter 4

THE BENEVOLENT PAST

This chapter looks backward, back to the end of the 19th century and the beginning of the 20th century. It examines the research others have conducted to identify the historical trends in resource availability over this period. Ultimately, we are concerned about the future, not the past, and past trends, of course, may not continue into the future. Nevertheless, an understanding of the past should prove useful when we turn our attention toward the future in Chapter 5.

This chapter is organized around our three economic measures of resource availability. It looks at trends in the costs of producing mineral products first, then in mineral commodity prices, and finally in user costs. The last section attempts to draw some general conclusions about past trends in resource availability and to explain some of the inconsistencies among the three measures.

Production Costs

Mineral producing companies do not generally make their production costs available to the public. Some consulting firms, government agencies, and even producing companies collect and estimate this information, primarily for what are called cash costs (which approximate variable costs, and thus exclude capital costs).[1] These series, however, go back at best only several decades.

As a result, efforts to measure production costs have focused on trends in the inputs used to produce mineral commodities.[2] This, for example, is the approach taken by Barnett and Morse (1963) in their pioneering book *Scarcity and Growth*, which Chapter 2 briefly notes. Using data compiled by Potter and Christy (1962) and Kendrick (1961), they construct indices of the labor used per unit of output and of the labor plus capital used per unit of output for all extractive industries. They also compute the same indices for agriculture, for minerals, for forestry, and for a number of specific industries within these economic sectors. Their study, which looks just at the United States, covers the period from 1870 to 1957.

It is important to note that Barnett and Morse measure the average labor and capital costs of resource production across all producers, and not the costs of marginal producers as one would ideally like. As a result, they tend to underestimate the labor and capital required by the marginal producers. This, however, may not greatly affect their results and findings. Since they are looking at trends over time, trends in an index of average costs may closely follow the trends in an index of marginal costs.

Table 4.1 shows their results when production costs are measured in terms of labor and capital inputs per unit of output. At the time the Barnett and Morse study appeared, these results created considerable surprise. They indicate that the labor and capital inputs needed to produce extractive resources in general declined dramatically—

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[1] See, for example, U.S. Bureau of Mines (1987) and Torries (1988, 1995).

[2] When physical measures of inputs are used, such as number of employees, this procedure does have the advantage that the results are not influenced by changes in wages and other input prices, whose movements presumably do not reflect resource scarcity.

by over 50 percent—during the nearly 90-year period examined, despite the dramatic growth in their consumption. Moreover, the pace of decline was greater after 1919 than before, suggesting not only that resources were becoming more available over time, but that they were doing so at an accelerating rate. Finally, the fall in production costs was even greater for the mineral sector—over 75 percent—although this sector unlike agriculture and forestry relies upon nonrenewable resources.

Barnett and Morse attribute these favorable trends largely to technological change. New technologies lower the costs of finding new resources. New technologies allow the exploitation of previously known but uneconomic resources. New technologies permit the substitution of less scarce resources for more scarce resources. New technology reduces the amount of resources needed to produce final goods and services. Moreover, according to Barnett and Morse (1963, pp. 9-10):

> These developments . . . are not essentially fortuitous. At one time they were, but important changes have occurred in man's knowledge of the physical universe over the past two centuries, changes which have built technological advance into the social processes of the modern world. . . . Not only ingenuity but, increasingly, understanding; not luck but systematic investigation, are turning the tables on nature, making her subservient to man. And the signals that channel research effort, now in one direction, now in another—that determine innovational priorities—are usually the problems calling loudest to be solved. Sometimes the signals are political and social. More often, in a private enterprise society, they are market forces.

The Barnett and Morse study, in large part because of its surprising findings, did not go unchallenged. Indeed, the study fostered a wave of research on resource extraction and processing costs that continues down to the present. Some writers (Cleveland 1991) question the focus on just labor and capital inputs, arguing the results might be quite different if energy and other inputs were also taken into account. Others, including Barnett (1979) himself, raise the possibility that production costs could be falling in the United States, thanks to that country's increasing reliance on imports, while rising for the world as a whole. Still others note that the rising environmental costs associated with resource production were not included in their figures. Finally, some commentators (Johnson and others 1980, Hall and Hall 1984) claim that extending the Barnett and Morse analysis beyond 1957 might uncover a reversal in the downward cost trend.

While all the above are legitimate concerns, the Barnett and Morse results have proven remarkably robust. Subsequent research (Barnett 1979, Johnson and others 1980, Slade 1988, Slade 1992, and Uri and Boyd 1995) on the costs of resource extraction has for the most part supported the Barnett and Morse conclusion that production costs have fallen since the late 1800s for resources in general, and particularly so for nonrenewable mineral resources.[3]

Mineral Commodity Prices

Mineral commodity prices enjoy two important practical advantages over the two other economic indicators of resource availability. First, they are readily available and easy to obtain. Second, they are reasonably reliable. This is particularly true for mineral prices set on commodity exchanges, such as the London Metal Market. As a result, there is a rich history of studies of mineral commodity prices.

This section looks first at the early studies undertaken in the 1960s and 1970s. It then focuses on the attempts to model the historical trends in mineral commodity prices that began in the 1980s. These early modeling efforts in turn fostered a number of more sophisticated models, in some instances employing new advances in time series analysis. They are considered toward the end of the chapter.

Early Efforts

Potter and Christy (1962) provide one of the first systematic analyses of price trends for natural resource commodities. This work covers a variety of agricultural, mineral, and forestry products in the United States. It spans the period 1870 to 1957, and was subsequently updated to 1973 by Manthy (1978). Nominal prices are converted to real prices by using the U.S. producer price index (PPI) to adjust for inflation.[4]

Figure 4.1, reproduced from Potter and Christy, shows the long-run price trends for all resources, and for the agricultural, mineral, and forestry sectors separately. It indicates that mineral prices fell by over 40 percent between 1870 and 1957. All this decline, however, took place during the first decade of this period. Since 1880, mineral prices display considerable short term fluctuations in response to wars and other disturbances, but the long term trend is quite stable. The data for all minerals, however, hide major differences in price trends among individual commodities. For example, the real prices of coal, lead, and lime rose over the 1870-1957 period, while those for iron, zinc, copper, petroleum, and phosphate rock fell.[5]

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[3] For an exception, see Hall and Hall (1984).

[4] The U.S. wholesale price index became the producer price index in 1978. To avoid confusion, this chapter refers to both by the current name, the producer price index, or by its abbreviation, PPI.

[5] Potter and Christy provide price data for four energy commodities (petroleum, natural gas, bituminous coal, and anthracite coal), for fourteen metals (iron ore, pig iron, steel, ferroalloys, ferromanganese, nickel, tungsten, copper, lead, zinc, bauxite, aluminum, tin, and magnesium), and for fourteen non-metallic minerals (dimension stone, crushed and broken stone, portland cement, lime, sand, gravel, clays, structural clay products, building brick, gypsum, phosphate rock, potash, sulfur, and fluorspar).

Barnett and Morse (1963) also examine the price data collected by Potter and Christy, deflating these data by the prices of non-extractive goods, rather than the PPI. Abstracting from short-run movements, they find mineral prices have remained quite constant since the last quarter of the 19th century. These findings are similar to those of Potter and Christy, and stand in sharp contrast to the dramatic decline Barnett and Morse find in the production costs of mineral commodities over the same period. Nevertheless, Barnett and Morse contend that trends in prices like those for production costs provide no support for the hypothesis that mineral depletion is causing resource scarcity

Writing a decade later, Nordhaus (1974) does find substantial declines in the long-run price trends for many important mineral commodities. Between 1900 and 1970, for example, his work shows a price drop of 97 percent for aluminum, 90 percent for petroleum, 87 percent for copper, lead, and zinc, 84 percent for iron, and 78 percent for coal. Nordhaus uses the cost of labor to deflate the prices of mineral commodities, which largely explains why his results differ from Potter and Christy and from Barnett and Morse. Over the years labor costs have risen much more rapidly than the prices of wholesale goods or of non-extractive goods.

These findings highlight the fact that long-run price trends may vary considerably depending on the deflator used to adjust for inflation. Nordhaus's deflator—labor costs—has the advantage that it shows trends in the number of hours of labor that one could buy for the price of various mineral commodities, a measure of opportunity costs that is easy to comprehend. On the other hand, labor costs have risen in part because of investments in human capital (more education, improvements in on-the-job training, better health), which have little or nothing to do with trends in mineral resource availability.

Econometric Models

Smith (1979) provides one of the earliest attempts to model mineral price trends. Relying primarily on the data of Potter and Christy (1962), as updated and modified by Manthy (1978), he postulates the following simple linear time trend over the 1900-1973 period for the real prices of four categories of natural resources (total extractive goods, mineral commodities, forestry products, and agricultural goods):

$$P_t = \alpha_0 + \alpha_1 t + \varepsilon_t \quad \text{. . . . .} \quad 4.1$$

Where P_t is the average price in year t for each of the natural resource categories deflated by the U.S. producer price index, t is the time trend (t = 1, 2, . . .74), ε_t is the stochastic error in year t, and α_0 and α_1 are unknown parameters, which are assumed to remain constant over the period.

Smith uses regression analysis to estimate the parameters, and finds that the estimates for the parameter of the trend variable (α_1) are statistically significant (in the sense that they differ from zero with a probability of 90 percent or more) only in the case of forest products. These results at first blush appear to support the conclusions of Potter and Christy and of Barnett and Morse that aside from the forestry sector there has been no significant trend over the long term in the real prices of natural resource products.

Smith, however, argues that this conclusion is warranted only if the parameters in his model (α_0, α_1) remain constant over the entire 1900-1973 period. Using two alternative statistical techniques,[6] he shows that this is highly unlikely. In the case of

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[6] The first is the Brown and Durbin cusum test, and the second the Quandt log-likelihood ratio.

minerals, his findings suggest that the estimate for the time trend parameter (α_1) was negative and rising toward zero over the decade from 1910 to 1920, implying that prices were falling over this period but at a slower and slower pace. The time trend parameter then turns positive during the 1920s and 1930s, implying that prices were rising over these years. It becomes negative again during the 1940s, 1950s, and early 1960s, and thereafter remains very close to zero until 1973, the end of the period examined.

These findings, he suggests, should not be surprising. Over the years 1900-1973 many changes affecting resource price trends were occurring. The nature of the U.S. economy was evolving, causing substantial shifts in the relative importance of individual commodities within the aggregate categories. Petroleum, for example, was becoming much more important both within the mineral sector and within the extractive goods sector as a whole.

Smith contends that these changes mean the long-run time trends that real resource prices are following have changed over the 1900-1973 period. As a result, the failure of real resource prices to rise over the long run may obscure more recent evidence covering a shorter period of time that may reflect growing resource scarcity. For this reason, he questions the conclusions of Potter and Christy and of Barnett and Morse.

Slade (1982), in an influential empirical study, argues that the true relationship between real resource prices and time is U-shaped.[7] In support of this hypothesis, she notes that the prices for mineral commodities should, under competitive market conditions, equal their marginal production costs plus user costs (as shown in Figures 2.1 and 3.2).

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[7] This possibility is also suggested by Pindyck (1978) and Heal (1981).

User costs according to Hotelling (as we saw in Chapter 2) should be increasing over time. Production costs, however, may be rising or falling. Slade contends that technological change tends to push extraction and processing costs down over time, while the need to exploit lower grade and poorer quality deposits tends to drive production costs up. For a time, the beneficial effects of technological change may offset the adverse effects of poorer quality deposits as well as the rise in user costs. In this case, production costs will fall by more than user costs rise, allowing real price to decline.

This favorable trend, however, cannot continue indefinitely. Over time production costs account for a smaller and smaller share of the sum of production costs and user costs, and so the rise in user costs must eventually more than offset the decline in production costs. Slade believes this reversal will be reinforced by natural limits on new technology that eventually cause even production costs to rise.

Figure 4.2 portrays the expected scenario. At the beginning of the period under analysis (T_0), user costs are quite small compared to marginal production costs. Early in the period, thanks to technological change, production costs fall sufficiently to offset the upward trend in user costs. This favorable trend continues until time T_1, after which the rise in user costs exceeds the decline in production costs, causing price to rise. Eventually, at time T_2, the downward trend in production costs is also reversed as the rise in costs caused by the decline in ore grade and deposit quality offsets the effects of new technology.

Slade tests this hypothesis for eleven important mineral commodities—three fuels (coal, natural gas, and petroleum) and eight metals (aluminum, copper, iron, lead, nickel, silver, tin, and zinc). She assumes the hypothesized U-shaped relationship between price and time can be captured by the following quadratic function:

$$P_t = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \varepsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4.2$$

Where P_t is the average price in year t for each of the eleven mineral commodity deflated by the U.S. producer price index, t is the time trend (t = 1, 2, . . .), ε_t is the stochastic error in year t, and α_0, α_1, and α_2 are unknown parameters.

For each commodity, Slade uses price data from 1870 (or the first year data are available) to 1978 and regression analysis to estimate the parameters (α_0, α_1, α_2) of equation 4.2. For comparison purposes, she also estimates the linear relationship, shown in Equation 4.1, between prices and time.

Her assumed U-shaped relationship between prices and time anticipates that the estimate for α_1 will be negative and the estimate for α_2 will be positive, a result that she finds holds for all eleven mineral commodities. Moreover, except for lead, the estimates for α_2, which indicate a non-linear relationship, are positive with probability levels that exceed 90 percent. These results provide strong support for Slade's hypothesis that mineral prices tend to fall and then rise over time. Moreover, in all cases she finds that the minimum point on the estimated relationship between price and time is reached before 1973. This, she concludes, ". . . indicates that nonrenewable natural-resource commodities are becoming scarce" (Slade 1982, p. 136).[8]

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[8] The results for the linear equation compared with those for the quadratic equation suggest that the latter more accurately reflects the true relationship between mineral prices and time. First, as noted, all but one of the estimated parameters for square of time variable in the quadratic equation are positive at the 90 percent probability level. If the true relationship between prices and time were linear, this parameter would be zero. Moreover, all of the estimated linear relationships considerably underestimate mineral prices toward the end of the period covered, which is not the case for the estimated quadratic relationships. Interestingly, the

Recent Developments

In large part because of its important implications for the long-run availability of mineral commodities, Slade's study has received considerable attention. Subsequent studies have raised a number of concerns or caveats about her analysis:

1. As we saw earlier, Smith questions whether one can assume the parameters of the simple linear model are constant over time. The same question can be raised for Slade's quadratic relationship.

In her article, Slade (1982, pp. 129,136) actually addresses this issue in passing. If the true relationship is as she assumes a quadratic function, with prices first declining but eventually rising, Smith should find the estimated parameter on the time variable when his linear equation is used to be negative in the early years of his sample, but declining toward zero. Eventually, it should turn positive, as real prices bottom out and start to increase. Slade claims this is what Smith's results show. A close look at his results for the mineral sector indicates that this is true for the period up to 1920, but not thereafter. This is not what we would expect if the quadratic equation with invariant parameters applied over the entire 1870-1978 period that Slade examines. Berck (1995) and Pindyck (1999) provide further evidence that the long-run relationship between mineral prices and time changes over time.

This is troubling, for its suggests efforts to estimate empirically such relationships are shooting at moving targets. Any given effort, particularly if it covers a long span of time, is likely to reflect a hybrid curve that reflects several different true relationships,

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results for the linear equation provide much less support for the conclusion that mineral resources are experiencing increasing scarcity. Only seven of the eleven estimated parameters on the time variable were each relevant over different periods with no guarantee that estimated results even closely approximate the current long-run relationship.

2. A related challenge comes from modern time series analysis, much of which was not available to Slade in the early 1980s when she wrote her original article. The statistical properties of her results, which so strongly support her hypothesis regarding the long-run trend in mineral prices, depend on mineral prices being what is called trend stationary. This means that the prices of mineral commodities will revert back to the same long-run trends if disturbed by a short-run shock, such as a strike or a war. If this is not the case, then prices follow a stochastic trend, and the parameters (α_0, α_1, α_2) change over the period examined in response to short-run shocks.

Several scholars (Agbeyegbe 1993, Berck and Roberts 1996, Ahrens and Sharma 1997), including Slade (1988), have subsequently carried out tests to determine if the price series for the mineral commodities she considers are trend stationary. The results vary, in some cases the trends are stationary, in other cases they are stochastic.

3. Slade’s analysis ends in 1978. As Krautkraemer (1998) shows in some detail, the prices for many energy and other mineral commodities fell during the 1980s and 1990s. This raises the possibility that her findings might be quite different if the study were carried out today.

Howie (2001) has recently updated Slade’s data, and the results are shown in the Appendix to this study. He also re-estimates her equations, using the same regression techniques and commodities. The results provide somewhat mixed support for Slade’s original findings. The quadratic function does a better job of tracking the long-run trends in mineral prices than the linear function for some but not all of her eleven commodities.

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positive, and only four of these at a probability of level of 90 percent or more.

Howie also finds that the price trends for certain commodities are stochastic not stationary.

4. Like most other scholars analyzing long-run price trends, Slade assumes that a commodity's price equals its marginal production cost plus user costs. Implicitly, she and others assume that the marginal production costs reflected in prices are those that prevail over the long-run, not the short run, for long-run production costs are what are relevant for measuring the long-run availability of mineral commodities.

We know that in the short run (a period so short that firms cannot change their capacity), when the demand for mineral commodities exceeds the available capacity, marginal production costs can for a time far exceed their long-run levels. On the other hand, when the economy is depressed and the mineral industries suffer from excess capacity, marginal production costs are likely to fall below their long-run levels. By examining mineral prices over a number of decades, Slade and others presume that such short-run deviations of production costs and prices from their long-run values more or less cancel out.

A more troubling problem arises when prices are not the outcome of the interaction of supply and demand in a competitive market. This can occur when producers acting individually or collusively exercise market power and control the market price. It can also occur during wars and other emergencies, when governments impose price controls on mineral commodities. Such market distortions have occurred with some frequency in the past, as Figure 4.3 illustrates for copper. During such periods, price is a biased indicator of availability, overestimating scarcity when cartels and other collusive activities maintain the price at artificially high levels and underestimating scarcity when price controls keep prices from reaching their market clearing levels.

Slade (1982, footnote 14) raises the possibility that the OPEC cartel and the increases in energy prices it produced after 1973 might account for the subsequent upturn in mineral prices. She dismisses this possibility, however, by noting that the estimated curves for all of the mineral commodities she examines reached their minimum point before 1973.

While the general public is well aware of OPEC's efforts to control the price of oil since 1973, less well known are the frequent attempts to control the price of copper, nickel, tin, and numerous other mineral commodities over the past century. Most of these efforts lasted for only a few years, but unlike the short-run impact of the business cycle on prices, there is no tendency for the effects of market power on price to cancel out over the long run.[9]

The available literature, unfortunately, provides few studies that systematically examine how market power alters the long-run trends in commodity prices. We do know that over the past century many non-fuel mineral markets have become more competitive as the costs of transporting bulk commodities have fallen and the demand for mineral commodities has grown. This suggests that long-run prices may underestimate trends in scarcity. Thanks to OPEC and its effects on oil and other energy prices since the early 1970s, just the opposite may be true for the energy markets.

Some years ago, Herfindahl (1959) conducted an interesting study of copper prices and costs, and found that the effects of market power can be substantial. Carefully examining the period 1870 to 1957, he identifies the years during this period that were abnormal, in the sense that collusion, wars, or depression seriously distorted the copper price (see Figure 4.3). He also divides the years before World War I from those after, since a revolutionary change in technology at around that time caused a one-time drop of some 37 percent in real prices. Of particular interest for our purposes, he finds that the copper price deflated by the producer price index (PPI) declined over the 1870-1918 period by five percent a year when the abnormal years were excluded, compared with four percent a year when they were included. For the 1918-1957 period, the difference was much greater: real prices increased by 0.2 percent a year when the abnormal years were excluded compared with 0.6 percent when they were included.

Herfindahl's work calls into question, at least for copper since 1918, the premise advanced above that a decline in market power over time has introduced a downward bias in our price measures of scarcity for the non-fuel mineral commodities. It also raises the possibility that long-run trends in the real prices of mineral commodities may contain breaks, or abrupt downward shifts, and thus fail to follow the smooth continuous trends so often assumed in studies (especially econometric studies) of mineral commodity prices. Finally, the Herfindahl study shows that systematic efforts to purge the distortions introduced by market power and other factors that cause prices to deviate from their market clearing values are possible.

5. Slade uses the PPI to deflate the nominal prices of mineral commodities. While this index is widely used, rarely is it justified beyond mentioning the need to eliminate the effects of inflation. There are, of course, other deflators one might use. As we have seen, Barnett and Morse (1963) find the prices of non-extractive goods most appropriate

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[9] For studies of cartels in the mineral and energy industries, see Eckbo (1976) and Schmitz (1995).

for their purposes. Nordhaus (1974) uses the cost of labor, and Krautkraemer (1998) the consumer price index (CPI). Another candidate is the GDP deflator.

Conceptually, the deflator used should depend on how we want to measure resource scarcity. This is done by considering the sacrifice, usually in terms of some basket of goods, that society has to give up to obtain an extra ton of copper or barrel of oil. If the desired sacrifice is a representative sample of all the goods and services that comprise the economy, then the GDP deflator is the most appropriate. If the desired sacrifice is a representative sample of all consumer goods and services, then the CPI should be used.

While either of these two baskets of goods is probably more appropriate than a basket of producer goods, the PPI, which Slade and many others use, has the advantage that it is available over an extended period of time. In addition, there is little to suggest that the long-run trends in real mineral prices would be significantly altered if the GDP deflator or CPI were used instead.

We do know from our earlier discussion of Nordhaus (1974) that using the cost of labor makes a big difference. Since labor costs have risen much more than the costs of most goods and service, deflating by labor costs produces real mineral prices that distinctly trend downward over the long run. Deflating by the cost of labor is appropriate when one desires to measure the sacrifice in terms of how much labor (leisure) one can buy for the price of an additional unit of a mineral commodity. As noted earlier, however, it suffers from the fact that the cost of labor has risen over time for reasons that have nothing to do with trends in resource scarcity. In addition, it implies that the appropriate basket of goods for measuring the opportunity costs contains just one good, labor services.

Perhaps a more serious shortcoming of the PPI, and of other commonly used deflators as well, arises from their tendency to overestimate inflation. Several years ago a Congressional Advisory Commission estimated that the U.S. CPI overestimates inflation by 1.1 percent a year (U.S. Senate, Committee on Finance 1966, Boskin and others 1998, Moulton and Moses 1997). Most of this bias (0.6 percent) is attributed to the introduction of new goods and improvements in the quality of existing goods. The rest reflects the failure of the consumer price index to account properly for consumer substitutions in response to price changes (0.4 percent) and for discount stores and other improvements in retailing (0.1 percent).

While these exact percentages may not apply to the PPI, there is no doubt that it too overestimates inflation for the same set of reasons. This would not be a problem if the reported prices for mineral commodities were similarly biased, but this is clearly not the case. Appropriate adjustments for quality changes, new products, and user substitutions would not significantly alter the long-run price for a particular grade of crude oil or for other mineral commodities. As a result, deflating nominal mineral prices by the PPI or any of the other common price indices generates long-run series of real prices that underestimate the true trends (Svedberg and Tilton, forthcoming).

Figure 4.4 provides some indication of the magnitude of this bias. It shows the real price of crude oil over the 1870-1998 period, deflated first by the PPI, then by the PPI minus 0.75 percent per year, and finally by the PPI minus 1.25 percent per year. The price for petroleum properly adjusted for inflation presumably lies somewhere between the last two curves. Not surprisingly, making this adjustment changes the course of long-run prices, causing them to trend significantly upward. A comparable change in the long-run trends for other mineral commodities occurs when their prices are similarly adjusted.

The above reservations about the Slade model raise legitimate concerns. What is less clear is how they, particularly when combined, affect her findings and the implications for the long-run availability of mineral commodities. We will revisit this issue at the end of this chapter.

User Costs

Our third economic measure of long-run trends in resource availability is user costs. As chapters 2 and 3 point out, user costs are the present value of the future profits that a mine loses as a result of increasing current output by one unit. Moreover, it is important to stress that the relevant mine is the marginal producer, as the current market price just covers its extraction costs plus user costs. Intra-marginal mines enjoy relatively low extraction costs thanks to particularly good ore or other considerations. So expanding current output by one unit causes intra-marginal mines to suffer a greater loss of future profits than marginal producers, but this loss reflects both user costs and the Ricardian rent associated with the quality of reserves (see Figure 3.2).

While Hotelling, Slade, and others anticipate on the basis of theory that user costs will rise over time at some fixed percentage rate, this result holds only under a fairly restrictive set of conditions, as Hotelling explicitly notes.[10] For example, Hotelling assumes only one homogenous ore (hence no differences in grade or other characteristics) and no technological change. Relaxing either of these assumptions allows user costs to follow other trends, including a decline over the long-run. Should the development of cheap solar power, for example, make the production of coal and natural gas uneconomic, the user costs associated with coal and natural gas production would fall to zero, since there would be no loss of future profits as a result of producing more today.

Thus, there is a need to measure trends in user costs. Not surprisingly, marginal mines do not report (and probably are not even consciously aware of) the expected net present value of the loss in future profits they incur by increasing their output an additional unit today. This means indirect measures of user costs are necessary. Assuming resource markets are competitive and certain other conditions, user costs reflect the in situ value (the value in the ground before extraction) of the reserves that the marginal mine owns and is exploiting. This in turn, again under the proper conditions, approximates the costs of finding such reserves. As a result, three indirect methods exist for estimating long-run trends in user costs for mineral commodities—the difference between their market price and marginal costs of production, the in situ value of marginal reserves, and the expected exploration costs of finding new marginal reserves.

None of these measures is easy to estimate over long periods due to the dearth of data and other problems. As a result, published studies on user costs are far less numerous than those on mineral prices. Moreover, the studies that do exist come to different conclusions. A few (Fisher 1981, Stollery 1983, Sadorsky 1991) find evidence of increasing user costs. Halvorsen and Smith (1991) fail to find any significant trend. Others (Farrow 1985, Pesaran, 1990, Lasserre and Ouellette 1991) conclude user costs are falling.

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[10] For a complete list of these conditions, see Chapter 2.

This somewhat confusing state of affairs is confounded further by other evidence, which suggests that user costs, while a fascinating intellectual construct, may be of little or no significance in practice. In particular, it is difficult, if not impossible, to find instances where mine managers have deliberately reduced profitable production on the grounds that the resulting increase in future profits, properly discounted, more than makes up for the loss in current profits. Indeed, it is rare to find mine managers who are even familiar with the concept of user costs.

The uncertainty created by new technology and other unexpected developments may simply make user costs largely or entirely irrelevant in the real world. Radetzki (1992), for example, points out that Sweden benefited greatly from the exploitation of its iron ore deposits from the beginning of the 20th century through the 1950s. However, the ability of these mines to compete, which was largely based on their close proximity to the steel industries of Europe, was undermined during the 1960s and 1970s by the technological revolution in the ocean transport of bulk commodities. Had Sweden decided to save these deposits in the hope of realizing even larger (discounted) profits in the future, the country would likely have reaped no benefits. In retrospect, the user costs of mining Swedish iron ore in the first half of the 20th century apparently were zero.

An Overview

The three economic measures just reviewed, as Chapter 3 points out, reflect different aspects or sources of scarcity. User costs focus on the availability of the resource in the ground. Marginal costs focus on the production process and its impact on availability. Prices reflect the combined effects of both trends in in situ availability and in production.

The available evidence on production costs indicates that the cost-reducing effects of new technology have more than offset the cost-increasing effects of the decline in the quality of the resources being exploited. As a result, production costs have fallen substantially for mineral commodities over the past century.

Historical trends in user costs and mineral commodity prices, on the other hand, are far less clear. In the case of user costs, obtaining reliable data over an extended period is quite difficult. This is not a problem for mineral prices, but interpreting the trends is. Some studies see long-run price as stationary, and conclude growing scarcity is not a problem. Others find trends following a U-shaped curve over time, and conclude that scarcity is on the rise. To this, one must add the problems of identifying the appropriate price deflator and the uncertainties they introduce.

Despite such inconsistencies, the available evidence does permit two general conclusions. First, over the past century, a period when the demand for mineral commodities exploded and the world consumed more mineral resources than all previous history combined, the depletion of mineral resources has not produced serious scarcity problems. The consumption of most mineral commodities today is as high as it has ever been. While the long-run trends in mineral prices may be confusing, they have clearly not forced the world to curtail its mineral consumption. As Krautkraemer (1998, p. 2091) has pointed out:

> Economic indicators of nonrenewable resource scarcity do not provide evidence that nonrenewable resources are becoming significantly more scarce. Instead, they suggest that other factors of nonrenewable supply, particularly the discovery of new deposits, technological progress

> in extraction technology, and the development of resource substitutes, have mitigated the scarcity effect of depleting existing deposits.

Second, the evidence from the past also strongly suggests that the long-run trends in mineral prices, and more generally in the availability of mineral commodities, are not fixed. Rather they shift from time to time in response to changes in the pace at which new technology is introduced, in the rate of world economic growth, and in the other underlying determinants of mineral supply and demand. This not only complicates the task of identifying the long-run trends that have prevailed in the past, but cautions against using those trends to predict the future. Since the trends have changed in the past, they presumably can do so as well in the future.

The lessons to be learned from the past, it seems, are nicely summarized by Neumayer (2000, p. 309) when he states:

> So far, the pessimists have been wrong in their predictions. But one thing is also clear: to conclude that there is no reason whatsoever to worry is tantamount to committing the same mistake the pessimists are often guilty of—that is the mistake of extrapolating past trends. The future is something inherently uncertain and it is humans' curse (or relief, if you like) not to know with certainty what the future will bring. The past can be a bad guide into the future when circumstances are changing. That the alarmists have regularly and mistakenly cried 'wolf!' does not *a priori* imply that the woods are safe.

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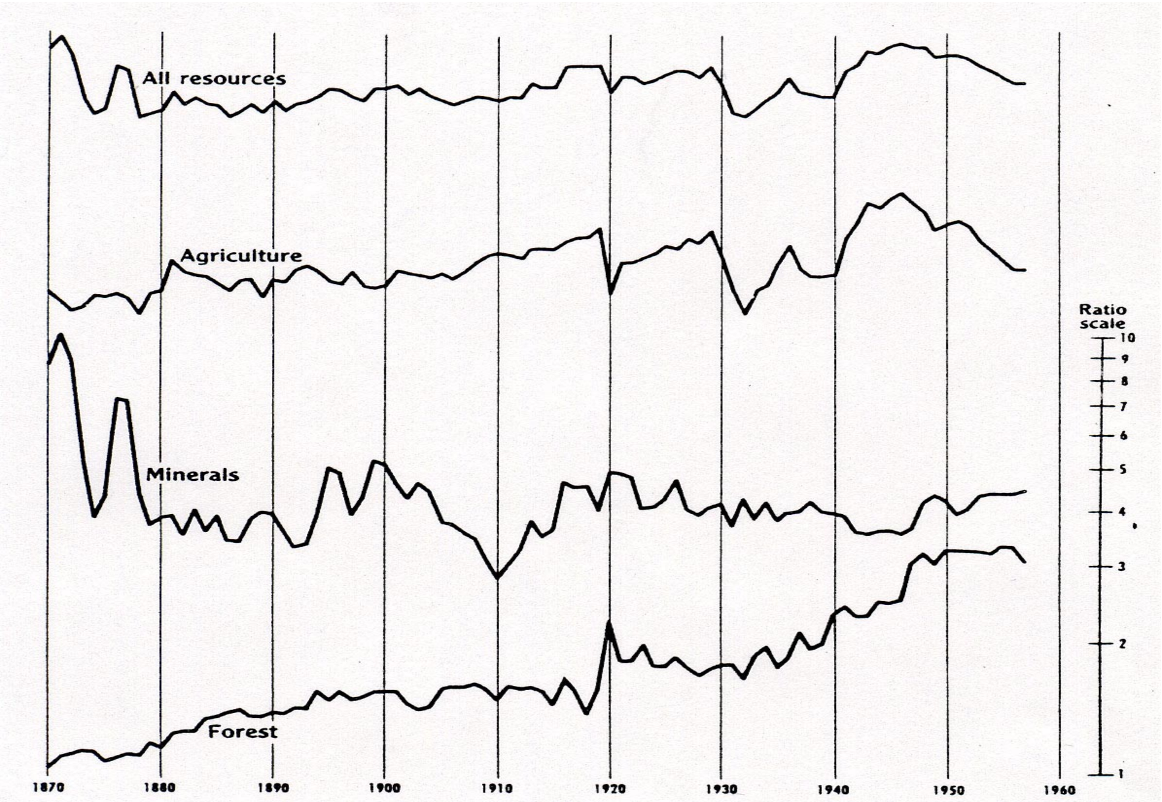
Table 4.1. Indices of Labor and Capital Inputs Per Unit of Output for the U.S. Extractive Industries as a Whole, for Agriculture, for Minerals, and for Forestry, 1870-1957
(1929 = 100)

	Total Extractive	Agriculture	Minerals	Forestry
1870-1900	134	132	210	59
1919	122	114	164	106
1957	60	61	47	90

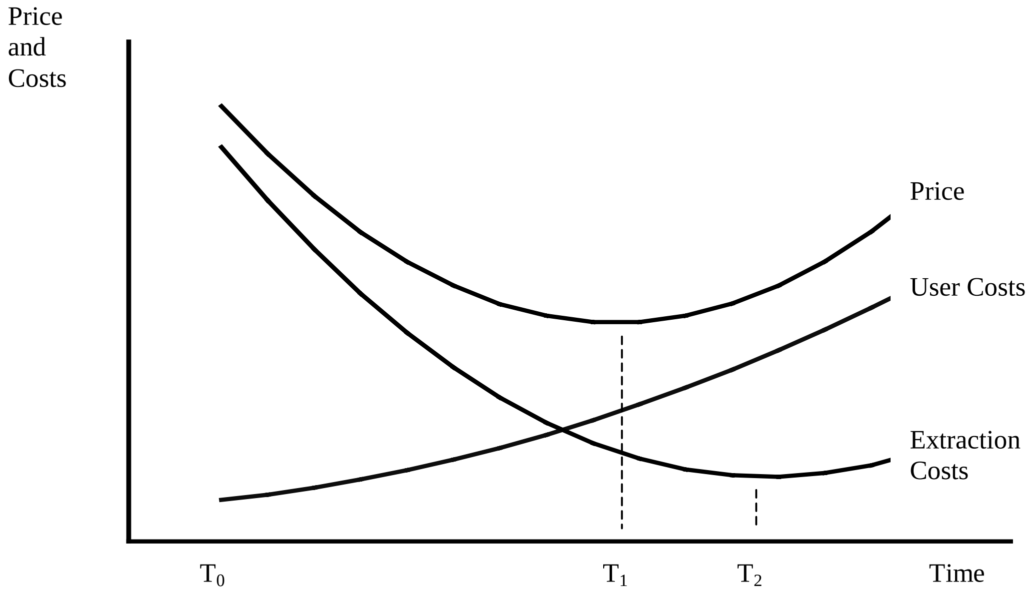
Source: Barnett and Morse (1963), p. 8.

Figure 4.1. Real Prices for All Resources and for the Agriculture, Minerals, and Forest Sectors



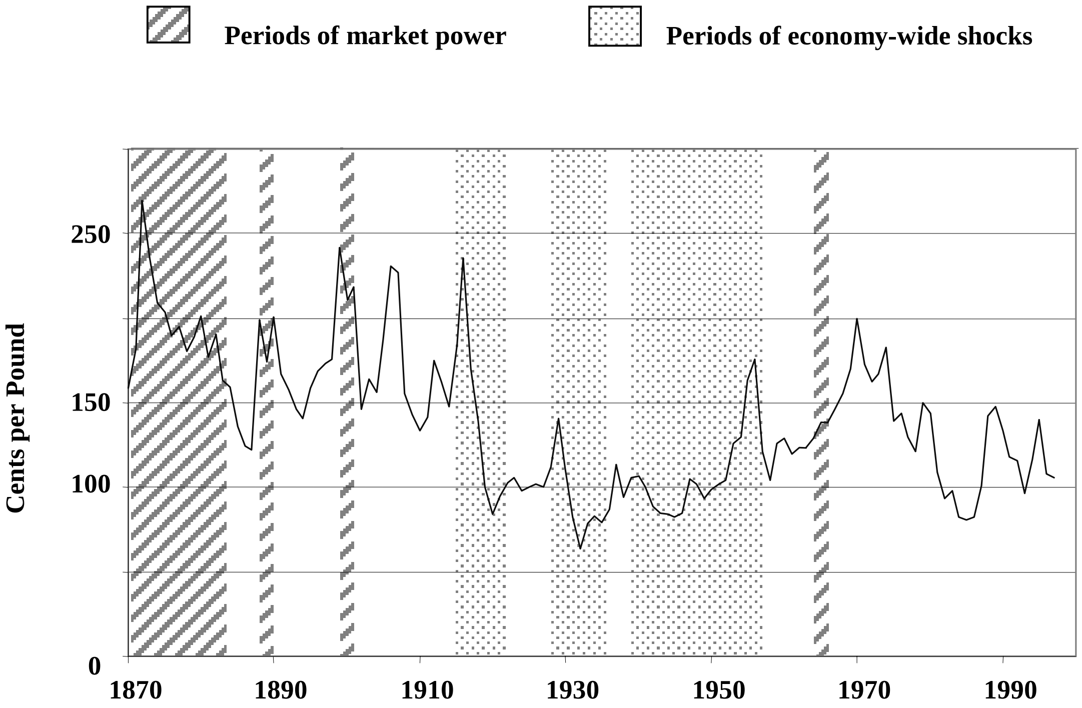
Source: Potter and Christy (1962), Chart 1.

Figure 4.2. Hypothesized Trends in User Costs, Production Costs, and Prices for Mineral Commodities



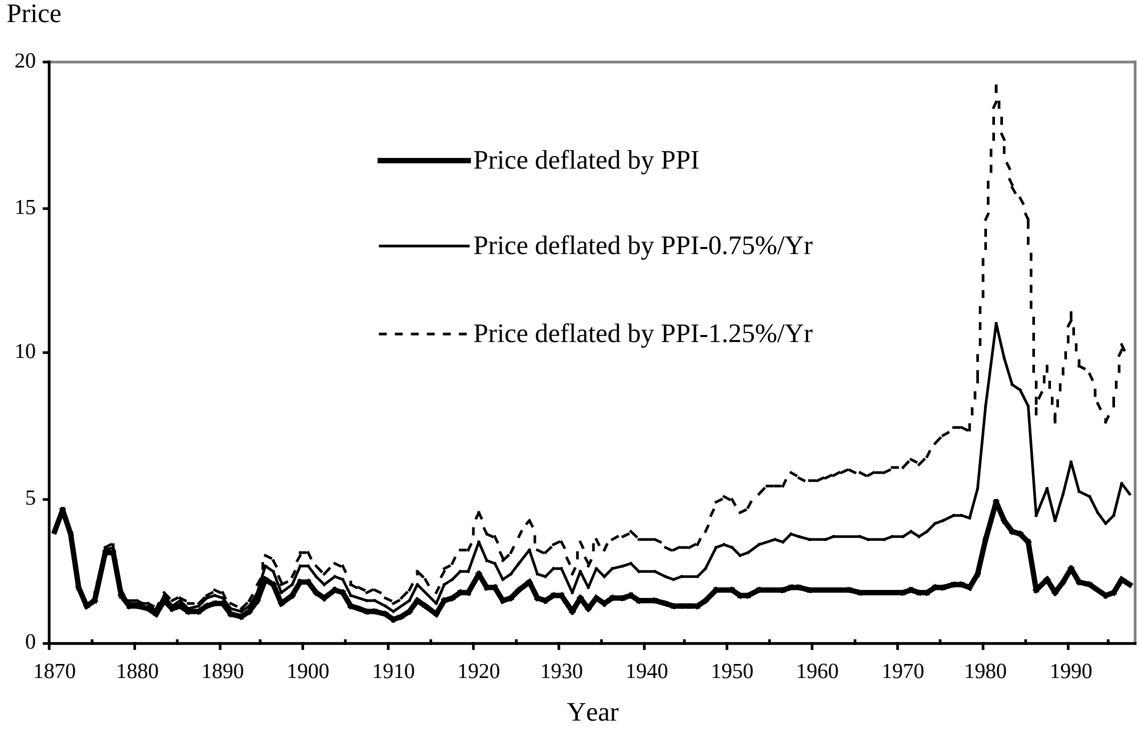
Source: A modification of Figure 1 in Slade (1982).

Figure 4.3. Real Copper Prices in 1997 Dollars Per Pound from 1870 to 1997 With Occurrences of Cartels, Wars, Major Depressions, and Other Market Distortions



Sources: Herfindahl (1957) and Mikesell (1979) as updated by Howie (2001)

Figure 4.4. Real Price of Petroleum Deflated by (a) the PPI, (b) the PPI Minus 0.75 Percent per Year, and (c) the PPI Minus 1.25 Percent per Year, 1870 – 1997, in (1870) Dollars per Barrel



Sources for oil prices deflated by the PPI: Potter and Christy (1962), Manthy (1978), Slade (1978), as updated by Howie (2001)