Chapter 2

EVOLVING CONCERNS

In an interesting little book, Maurice and Smithson (1984) examine a sample of resources crises confronting various civilizations at different points in history. The first and perhaps most significant was a food shortage some 10,000 years ago that led to the first agrarian revolution. Up to that point, the authors argue, the carrying capacity of the environment was sufficient to allow hunters and gatherers to survive and even prosper. At about 8000 BC, this changed, probably as a result of both population growth and adverse climate changes. Fortunately, some of our early nomadic ancestors responded by settling down, raising domesticated animals, and growing crops.

A second crisis, they contend, contributed to the end of the Bronze Age and the beginning of the Iron Age in ancient Greece around 1000 BC. The invasion of the Philistines, the Dorians, and others into the eastern Mediterranean at about this time interrupted trading routes, and for nearly a century cut Greece off from the traditional sources of tin it needed to make bronze. Out of necessity, the Greeks developed the means to produce iron.

These two developments suggest that resource shortages, and presumably concerns over resource availability, can be traced far back in time. For our purposes, however, it is sufficient to start with the Classical economists writing at the end of the 18^{th} century and the beginning of the 19^{th} century.

Classical Economists, 1798-1880

Among the Classical economists, Thomas Malthus is the best known for his views on resource availability and the human condition. His first published work, *An Essay on the Principle of Population*, appeared anonymously in 1798 and was republished under his name in five subsequent editions during his lifetime. In this influential treatise, he argues that population left unchecked tends to grow continuously while tillable land is limited. As more and more labor works the available land, output per worker falls until it reaches that level just sufficient to sustain life. At this point, misery or vice prevents further population growth. In his second edition, Malthus introduces the possibility that "prudential constraint" might limit population growth before living standards fell to the subsistence level. Despite this important qualification, the public generally associates Malthus with a very pessimistic view of the prospects for human welfare. Indeed, thanks in part to his writings, economics over the years has gained the reputation as the dismal science.

David Ricardo extends Malthus' analysis in his *Principles of Political Economy and Taxation*, first published in 1817. Most importantly, he takes into account quality differences in agricultural land. He assumes the best or most fertile land is worked first. As population increases and the demand for food rises, more land of poorer and poorer quality is brought into production. As food prices increase to cover the higher costs of farming the marginal fields, the owners of the more fertile lands earn a surplus, commonly referred to as economic rent or Ricardian rent. Output per worker also falls as in Malthus' world. However, the reason for the decline is the inferior quality of the new lands brought into production, rather than the addition of more workers to a given amount of (similar quality) land.

While Malthus ignores mining and nonrenewable resources, Ricardo points out that mineral deposits vary in quality just like land. As a result, he claims, his analysis of land is equally applicable to minerals. He also recognizes that it is possible to discover new mineral deposits and to develop new mining technology. Interestingly, though, he does not consider the depletable nature of mines, and so fails to focus on what many consider to be the fundamental difference between nonrenewable and renewable resources.

In certain ways, Ricardo is both more and less pessimistic than Malthus. Resource availability in his analysis causes declines in labor productivity either immediately or at the time that poorer quality land is first brought into production. With Malthus, problems arise only after all the available agriculture land is in use. On the other hand, in Ricardo's world it is always possible to bring more land into production, as long as declining fertility is tolerated.

John Stuart Mill, the last of the Classical economists we consider, develops the views of both Malthus and Ricardo in his *Principles of Political Economy*, which first appeared in 1848. Mill argues that Ricardian scarcity, arising from the need to exploit land of poorer fertility, will likely occur long before all the land available for agriculture is brought into production. Indeed, he contends that the land available for agriculture is far more extensive than Malthus presumes. He also argues that the adverse effects of uncontrolled population growth may very well encourage people to constrain population growth before living standards are driven down to subsistence. He recognizes as well that new technology could offset the tendency for resource scarcity to reduce living standards. For these reasons, his view of the human condition is more optimistic than those of Malthus and Ricardo.

The Conservation Movement, 1890-1920[1]

Widespread public concern over resource availability resurfaced toward the end of the 19th century in the Conservation Movement. Industrialization coupled with the closing of the American frontier and the rapid exploitation of once vast forest lands fostered this development, which was largely a political and social movement. Unlike Malthus, Ricardo, and Mill, the leaders of the Conservation Movement were not economists. Some, such as Theodore Roosevelt and Gifford Pinchot, were public officials. Many others were natural scientists.

As a result, the considerable literature associated with the Conservation Movement displays no coherent economic core. A reduction in physical supply is directly equated with a decline in resource availability, as the following frequently cited excerpt from *The Fight for Conservation* (Pinchot, 1910, pp. 123-24) so nicely illustrates:

> The five indispensably essential materials in our civilization are wood, water, coal, iron, and agricultural products. . . . We have timber for less than thirty years at the present rate of cutting. The figures indicate that our demands upon the forest have increased twice as fast as our population. We have anthracite coal for but fifty years, and bituminous coal for less than two hundred. Our supplies of iron ore, mineral oil, and

[1] This section is largely based on the interesting chapter (Ch. 4) on the Conservation Movement found in Barnett and Morse (1963), which in turn draws from Hays (1959).

> natural gas are being rapidly depleted, and many of the great fields are already exhausted. Mineral resources such as these when once gone are gone forever.

The Conservation Movement also viewed natural resources and nature as more multidimensional, with the various components more interdependent, and the whole far more complex than the Classical economists. Accordingly, mankind's critical dependence on nature is not just economic, but also psychological and even spiritual. Nature in its wonder promotes human values. Conservation is the "wise use" of resources, which goes far beyond the economist's concept of efficiency. It entails using where possible renewable resources in place of nonrenewable resources, more abundant nonrenewable resources in place of less abundant nonrenewable resources, and recycled products in place of primary resources.

While the Conservation Movement was largely concentrated in North America during the 1890-1920 period, similar concerns emerged in other industrializing countries and in other time periods. W. Stanley Jevons (1865), for example, warned Britain that its future industrial growth was threatened by the country's limited coal resources.

World War II and the Early Postwar Period, 1940-1965

During the 1930s the world was largely preoccupied with the Great Depression. Toward the end of this decade and throughout the first half of the 1940s, concerns over resource availability returned, but they focused on the short-run issue of securing adequate supplies for the war effort. Shortly after the war, however, the long-run availability of mineral resources once again rose to prominence as the world examined the implications for resource use first for reconstruction and then for long-run economic development. In the United States, these concerns led to the creation of the President's Material Policy Commission, more popularly known as the Paley Commission after its chair, William S. Paley. The Commission, which published its hefty five-volume report in 1952, assessed the adequacy of the world's mineral resources to meet future needs. In the words of Volume I (President's Materials Policy Commission 1952, p. 2):

> The nature of the problem can perhaps be successfully over-simplified by saying that the consumption of almost all materials is expanding at compound rates and is thus pressing harder and harder against resources which, whatever else they may be doing, are not similarly expanding. This Materials Problem is thus not the sort of "shortage" problem, local and transient, which in the past has found its solution in price changes which have brought supply and demand back into balance. The terms of the Materials Problem we face today are larger and more pervasive.

The Paley Commission report encouraged the Ford Foundation in 1952 to provide the funding needed to establish Resources for the Future, a nonprofit corporation for research and education in the development, conservation, and use of natural resources. Over the next several decades, Resources for the Future sponsored a number of studies on the long-run availability of mineral resources, including the influential study by Barnett and Morse (1963), one of two seminal works that shaped the debate over the long-run availability of mineral resources during the latter half of the 20th century.[2] The other, discussed at the end of this chapter, is the article by Harold Hotelling (1931) on "The Economics of Exhaustible Resources."

[2] A sample of other studies on resource availability that Resources for the Future has sponsored over the years includes Adelman (1973), Bohi and Toman (1984), Darmstadter, Dunkerley, and Alterman (1977), Herfindahl (1959), Kneese, Ayres, and d'Arge (1970), Landsberg and Schurr (1968), Manners (1971), Manthy (1978), Potter and Christy (1962), and Smith (1979).

Barnett and Morse draw a sharp distinction between the physical availability of resources and economic scarcity. During the latter half of the 19th century, for example, the actual and potential supply of whale oil declined as many species of whales were hunted almost to extinction. The development of low-cost petroleum products and electricity, however, filled the needs previously satisfied by whale oil, and so prevented this physical decline from producing economic scarcity.

Using measures of economic scarcity, Barnett and Morse find that both renewable and nonrenewable resources, but in particular nonrenewable mineral resources, have become more, not less, available between 1870 and1957, the period they examined, despite the explosion in resource use during the 20th century. They attribute this favorable outcome largely to technological change, and its ability to offset the adverse effects of resource depletion. This surprising finding, which stood in stark contrast to the perceived wisdom of the time, stimulated a research boom in this area.[3] In Chapter 4, we will return to the Barnett and Morse study and the subsequent literature it spawned.

Limits to Growth and Social Costs, 1970-2000

In investing, it is often said, timing is everything. The same may hold, at least on occasions, for academic publications. In 1972, Donella H. Meadows and her fellow authors published their book *Limits to Growth*. Using an analytical technique called systems dynamics, they construct a model that generates scenarios of world futures. In

[3] Chapter 2 of Barnett and Morse (1963) entitled "Contemporary Views on Social Aspects of Resources" contains an interesting survey of the views of government and various disciplines (naturalism, ecology, demography, political science, and economics) prevailing at the time this book was written.

their base-case scenario, the one that they believe most likely to evolve barring corrective public policies, they foresee the collapse of per capita food and industrial output as a result of the exhaustion of mineral resources by the middle of the 21^{st} century. While the study was severely criticized, it nevertheless was widely read and very influential, thanks in large part to its timing.

Shortly after the book appeared, the Middle East OPEC countries imposed an embargo on oil exports to the United States and the Netherlands for their support of Israel during the 1973 Middle East war. Simultaneously, OPEC as a whole engineered a three-fold increase in the world price of oil by withholding exports. Prices for many other mineral commodities also rose sharply in tandem with an economic boom in North America, Western Europe, and Japan.

Of course, temporary shortages caused by embargoes, cartels, and economic booms do not necessarily mean depletion is a problem. Still, the dislocations, though temporary, were painful, aggravated in part by market controls in some consuming countries that prevented commodity prices from rising to their market clearing levels. These problems focused public attention on resource availability in general and on *Limits to Growth* in particular. Many saw the disruptions of the early 1970s as an early warning that depletion and much more permanent and serious shortages were in the offing.

The widely expected scarcity, however, failed to emerge during the 1980s and 1990s as the real price of oil and many other mineral commodities actually declined. As a result, fears of resource depletion, though they did not evaporate completely, did subside. They were replaced by growing concerns over the environmental pollution and other social costs, such as the loss of biodiversity, indigenous cultures, and pristine wilderness, associated with mineral extraction and processing. The following quotes, the first by an economist (Young 1992, p.100) and the second by a geologist (Kesler 1994, p iii), reflect this shift in concern:[4]

> Are we running out? Recent trends in price and availability of minerals suggests that the answer is 'not yet' . . . . The question of scarcity, however, may never have been the most important one. Far more urgent is, Can the world afford the human and ecological price of satisfying its voracious appetite for minerals?
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> At the end of the twentieth century, we are faced with two closely related threats. First, there is the increasing rate at which we are consuming mineral resources, the basic materials on which civilization depends. Although we have not yet experienced global mineral shortages, they are on the horizon. Second, there is the growing pollution caused by the extraction and consumption of mineral resources, which threatens to make earth's surface uninhabitable. We may well ponder which of these will first limit the continued improvement of our standard of living. . . .

Another interesting example of this shift is *Beyond the Limits* (Meadows and others 1992), a sequel to *Limits to Growth*, written for the 20th anniversary of the latter's publication. Like the original volume, *Beyond the Limits* uses a systems dynamics model to generate scenarios of the future. The base-case scenario in both studies sees modern civilization collapsing during the 21st century. In *Beyond the Limits*, however, it is the environmental damage arising from the production and use of resources, rather than resource exhaustion, that causes the collapse.

Hotelling and the Theory of Exhaustible Resources

[4] There were earlier writers who anticipated the concern over the environmental constraint on resource exploitation of the 1990s. See, for example, Brooks and Andrews (1974).

While the preceding discussion brings us up to the present, it omits an important development that Harold Hotelling (1931) fathered with his article on “The Economics of Exhaustible Resources.” In this piece, Hotelling explores the optimal output over time for a mine with a given amount of known resources. To simplify the problem, he makes a number of strong assumptions: (1) The mine’s goal or objective is to maximize the present value of its current and future profits. (2) The mine is perfectly competitive and so has no control over the price it receives for its output. (3) There is no uncertainty, so the mine knows the size and nature of its resource stock as well as current and future costs and prices. (4) The mine’s output is not limited by existing capacity or other constraints, allowing the mine to produce as little as nothing and as much as its entire remaining resource stock during any particular time period. (5) The mine’s resource stock is homogeneous, so grade and other qualities do not vary. (6) There is no technological change.

Under these conditions Hotelling shows that firms exploiting an exhaustible resource stock behave differently than firms in other industries where all inputs are unconstrained. The latter, following the principles of any introductory economics textbook, maximize the present value of their profits by continuing each period to expand their output up to the point where the extra or marginal costs of producing one more unit just equal the prevailing market price.

Resource firms, on the other hand, have to take into account that each unit of output today means less profit in the future. In a world where ore is homogeneous, increasing output by one unit today results in a reduction of output by one unit in the final period of operation and the loss of the profits associated with that unit. In a world where the ore is heterogeneous, an increase in output today means the future must exploit poorer quality resources, causing higher costs and lower profits.

So in addition to the marginal costs of producing an additional unit, there is an opportunity cost, commonly referred to as user costs, scarcity rent, or Hotelling rent, which equals the present value of the lost future profits. As a result, a resource firm has an incentive to expand its output during any particular period only up to the point where marginal costs plus user costs equal the market price. Figure 2.1 illustrates this difference. The firm with a fixed resource stock produces at Q_1. The firm without fixed inputs expands its output to Q_2.

Since user costs are the present value of the lost future profits associated with a unit increase in current production, they also reflect the present value of the extra future profits a firm would realize from having the additional resources needed to produce one more unit of output. This means that user costs measure the current value of an additional unit of mineral resource in the ground. Moreover, in the world of Hotelling where the mineral resource stock is homogenous, user cost multiplied by the available mineral resource gives the current value of the total stock of the mineral resource in the ground.

Hotelling also points out that mineral resources in the ground are assets, and so they must under his assumptions earn a rate of return (r) comparable to other types of assets with similar risks. If this were not the case, if the rate of return on mineral resources were lower than that of other comparable assets, it would pay their owners to extract and sell these assets as soon as possible, and invest the resulting profits in other assets whose returns were higher. This behavior, which would drive down mineral prices in the current period and raise them in later periods (when less would be available), would continue until the rate of return from holding mineral resources in the ground just equals the rate of return on other comparable assets. Conversely, if the rate of return on mineral resources were higher than that of other comparable assets, the owners of mineral resources would be reluctant to exploit them. This would drive current prices up and future prices down, and in the process cause the rate of return earned by holding mineral resources to decline until it reached that of other assets.

This theoretical finding has important implications for mineral availability. Specifically, it anticipates that mineral resources in the ground should become less available as their value or price rises exponentially over time at the rate of r percent, where r is the rate of return on other comparable market assets.

For several decades Hotelling’s article attracted little attention. Since the 1960s, however, some of the best minds in the field of economics have focused on this topic, attracted in part by the challenge of solving complex intertemporal optimization problems with new developments in advanced mathematics. The resulting literature, which is reviewed in Peterson and Fisher (1977), Bohi and Toman (1984), Krautkraemer (1998), and Neumayer (2000), relaxes many of Hotelling’s assumptions. It also extends the scope from the optimal behavior for an individual mine to the optimal behavior for society as a whole in light of the finite nature of resources. These more recent works take into account exploration and the discovery of new mineral deposits, technological change from exploration to the reuse of mineral commodities, ore bodies with different grades and qualities, uncertainty and imperfect knowledge, market power that allows firms some control over price, and firm objectives other than maximizing the present value of current and future profits.

Relaxing Hotelling's assumptions, not surprisingly, alters his findings. No longer does the value of mineral resources in the ground have to rise at r percent over time. Indeed, with exploration and new technology, the value of mineral resources in the ground may even fall, implying that resource availability is increasing. Nevertheless, Hotelling's article and the subsequent work it stimulated play an important role in our understanding of the long-run availability of mineral resources. In particular, we will return to Hotelling and other works on the theory of exhaustible resources in the next two chapters.

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Figure 2.1. Market Price and Optimal Output For Mineral Commodity Producers