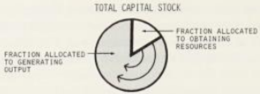

Figure 5-11 Shift over time in the fraction of capital that must be allocated to obtaining resources

Adelman: "This is the basic paradox of mineral economics. At any given moment, man is running down his limited stock of minerals, and running up the cost of their extraction. Yet as time passes, real costs and prices fall more often than they rise" (Adelman 1970, p. 132). The resolution of the paradox derives from continuing advances in technology. Adelman (1970) states that "improved technology usually more than offsets the tendency to rising cost (Adelman 1970, p. 131)."

It is clear that in the past, advancing technology has enabled man to tap sources of lower and lower quality at the same or lower relative unit cost, and we may assume that the unit cost reflects the fraction of capital allocated to obtaining resources. Advancing technology thus tends to reduce the fraction of capital allocated to obtaining resources by increasing the productive efficiency of each unit of capital. This effect of technology was included in the model and is described in detail in the section defining the equation for the fraction of capital allocated to obtaining resources FCAOR.

Will technology continue to offset the tendency toward rising costs forever? Ayres and Kneese give five convincing arguments for expecting resource costs to rise in the future as more resources are depleted:

> 1. Lower quality ores in some important materials do not necessarily exist in exploitable quantities. This appears to be the case for lead and zinc [Brooks 1967]. The same is probably true for practical purposes with regard to hydrocarbons *as such* (i.e., for nonfuel purposes) since hydrocarbons are not simply dispersed by consumption but are actually used up—that is, chemically transformed into CO_2 and H_2O. Thus we face the likelihood that hydrocarbons will ultimately become rather scarce resources, being replaceable only from natural photosynthesis or by chemical synthesis involving large expenditures of energy.
>
> 2. The increased output of the extractive industries in the last century can be attributed in part to the opening up of previously unexplored areas (e.g., Canada, Siberia, Africa, Brazil, Australia). Except for the ocean bottom—which is not easily accessible or easy to exploit—"new" sources will become rarer and rarer in the future.
>
> 3. The prices of mineral commodities historically have not reflected social costs arising from pollution and waste disposal. But these costs evidently increase nonlinearly as the amount of processing increases (requiring more energy and more technological inputs) and human settlement becomes more dense. We anticipate that in the long term social costs of obtaining new materials will mount greatly. Low prices have also been subsidized to some extent by devices such as "depletion allowances."
>
> 4. The increased productivity of the extractive industries in the last century is also partly due to economies of scale and the application of mechanical technology. Both are probably subject to the law of diminishing returns. That is, the effort and investment required to achieve further productivity gains in the future will probably be much greater than has been true in the past.
>
> 5. The developed countries (except for the Soviet Union) are rapidly using up their domestic high-grade sources of minerals and fossil fuels and becoming dependent on the less-developed nations. The latter, in turn, rely on raw material exports for foreign exchange to purchase needed technological goods and services. It is not unlikely that raw material exporters will increasingly band together to multiply their bargaining power and increase their revenues from this source (this—apart from successful war by the rich nations on the poor—is, in fact, one of the more plausible scenarios for achieving a fairly radical redistribution of wealth and technology in the world). [Ayres and Kneese 1971, pp. 12–13]

Technology was not included explicitly as a single variable in World3, for we regard present trends in technology as integral parts of many different system relationships and new technologies as important policy tools still available but not yet utilized by society. The effects of technology were included implicitly in some model variables in the resource sector (such as the fraction of capital allocated to obtaining resources FCAOR) to the extent warranted by past and probable future trends. We believe an advance in technology beyond these probable trends is properly viewed as an exogenous policy variable.

New technologies can affect two relationships in the nonrenewable resource sector when applied as exogenous policy variables. First, the implementation of new advances in technologies of exploration, extraction, and production can further decrease the fraction of capital that must be allocated to obtaining the resources necessary to sustain industrial output at any given level of remaining resources. Second, the implementation of new technological advances that improve the quality of products (and thus product lifetimes), increase recycling, or reduce the quantity of resources needed in each product tend to decrease the per capita resource usage rate. These effects are discussed in detail in the section on model equations (5.5) and tested in the section on simulation runs (5.6).

5.4 CAUSAL STRUCTURE

The observed long-term behavior of the world's nonrenewable resource system can be summarized as exponential growth in resource usage and a tendency toward rising costs of obtaining resources, which has historically been offset by technology. To explain these trends, the underlying assumptions in the model are:

1. The finite stock of nonrenewable resources constantly decreases over time.
2. The capital costs of obtaining resources increase as the accessibility (grade, depth of deposit, location) of those resources deteriorates.