literacy, and mortality) and institutional forms are characteristic of much poorer nations.

Given the data in Figures 3-3 and 3-4, one can infer the approximate average industrial output per capita IOPC that has historically corresponded to any GNP per capita. Thus the empirical relationship of any factor, such as fertility, with GNP per capita can be converted to a function of IOPC. This conversion was employed throughout the model.

While one could weight and sum the four components of output in the model —services (1968 dollars per year), industrial output (1968 dollars per year), food (vegetable-equivalent kilograms), and resources (resource units per year)—to derive a crude measure of total world output, this process does not appear to be useful in understanding the causes and consequences of long-term growth in population and material output. Short-term governmental decision making is strongly influenced by forecasts of a policy's impact on GNP. However, both the market prices and the relative magnitudes of the components of the globe's GNPs will change so radically over the next century that little useful information is gained by attempting to derive aggregate product figures from the model's output. Thus no measure of gross world product is calculated in World3.

Exclusion of Labor

It appears that there has always been unemployment. The global stocks of industrial, service, and agricultural capital have never provided full-time jobs to the entire global work force. While there have been local shortages of workers skilled in specific trades, growth in the capital stock tends to occur in those sectors where labor is adequate. Thus we assumed that labor constraints will not limit the total output that can be produced by the various capital stocks over the next century. As a consequence, the production functions in World3 do not include labor as a causal factor. The ratio of total population to output will influence the composition of output. That relationship is included in World3.

It is likely that a severe decline in population would create labor shortages and thus decrease the efficiency of the global industrial capital plant. For this reason, there is a simple labor sector in World3 that affects the model's behavior only if the population declines faster than the industrial capital base. (This effect of labor will be described later in this chapter.) During the period of growth and equilibrium in World3, however, there is no substitution between capital and labor. The World3 industrial production function is a simplified version of the type developed by Harrod (1948) and Domar (1957) and discussed in detail by Allen (1967). It has fixed input coefficients:

$$Q = \min\left(\frac{\text{capital}}{\text{capital-output ratio}}, \frac{\text{labor}}{\text{labor-output ratio}}\right)$$

Because of the social implications of unemployment, we consider the exclusion of labor to be one of the least satisfactory simplifications of the global model. Although the inclusion of an explicit labor force and a representation of the causes and consequences of unemployment are unlikely to change the basic behavior modes of World3, these additions would make the model much more relevant to studies of social welfare and political stability. Global unemployment, which is an immense problem today, is expected to worsen over the next several decades. It would therefore be useful to extend the model to include the causal mechanisms in which unemployment is involved.

Depreciation of Capital

As industrial capital is used to produce output, its productivity gradually decreases. Buildings deteriorate and equipment wears out. In calculating the value of an organization's assets, accountants recognize this loss in productive efficiency by subtracting an annual depreciation from the value of each organization's capital. One computational method for determining the magnitude of the depreciation employs the concept of a "declining balance" of capital. Each year a certain percentage, related to the lifetime of the capital, is deducted from the balance of capital remaining. The result is an exponential decline in the calculated value of each unit of capital. The relationships among the initial value, or purchase price, of a capital unit, its expected lifetime, and the value assigned to the capital unit over time are shown in Figure 3-9. For comparison, Figure 3-9 also illustrates the value over time of a capital unit that does not depreciate until it is discarded at the end of its productive lifetime.

In most cases the productivity of capital deteriorates through use. Moreover, some capital is discarded prematurely while other capital is used long beyond the period of use characteristic of items in its class. Thus the declining-balance approach appeared to be appropriate for use in World3. We approximated the depreciation of each capital stock by subtracting annually an amount equal to the quotient of capital and average lifetime of the capital (quantity of capital/average lifetime of capital).

If we combine in one causal structure the concept of declining-balance depreciation, our definitions of four capital and output categories, our emphasis on physical rather than financial flows, and a simple Harrod-Domar production function, it is possible to explain the two behavior modes—growth and shifting output composition—that characterize the global economy.

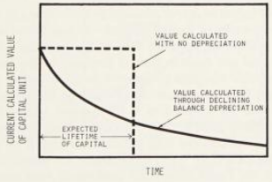

Figure 3-9 The current value of capital as a function of time, the capital's initial value, the expected lifetime of the capital, and the depreciation method