decline by moving the limiting factor from one sector to another sector. As each new technology is implemented, growth is allowed to continue until growth-limiting pressures arise elsewhere. Eventually in Run 7-17 growth is again halted by the effects of resource depletion, the same mechanism that was active in the reference run (Figure 7-7). The combined effects of large advances in resource, pollution, and agricultural technologies manage to postpone the eventual decline by less than 100 years.

Perhaps of more significance than the timing of the eventual decline exhibited in this series of runs is the fact that a technological response to approaching growth limits does not lead to a smooth accommodation with those limits. A technological response does not normally reduce the delays in the response of the world system to growth, nor does it weaken the positive feedback mechanisms causing growth. The physical limits are effectively raised, but not raised indefinitely; thus all the properties that lead to the unstable overshoot mode are still present in the system. To remove the property of physical limits completely, the process of developing technological solutions to expand the ultimate limits must be exponential; in fact, their growth rates must be faster than the exponential growth rates of population and capital. The next section presents a simulation run to illustrate this point.

Exponential Changes in Technology

The preceding set of technological runs showed that discrete changes in technology only tend to postpone overshoot and decline in the world model. Run 7-18 (Figure 7-23) shows the behavior of the model if one assumes that all the ceilings to growth in the model are lifted exponentially at 4 percent per year beginning in 1975, and at no cost. Under these conditions, the model no longer exhibits the overshoot and decline mode of behavior. Industrial output per capita IOPC continues to grow exponentially throughout the model run, and in fact could keep on growing forever. Food per capita FPC grows very quickly after 1975 and eventually stabilizes near the maximum indicated level of food per capita. Although the crude birth rate CBR declines continually throughout the 200-year period, it remains slightly higher than the crude death rate CDR throughout the run. Therefore, population POP continues to grow throughout the model run, reaching 14 billion people in the year 2100. The index of persistent pollution PPOLX remains at very low levels, and resources are being depleted very slowly by the year 2100. What changes had to be made to obtain such a different behavior mode from the same model?

Because the output of this technological run is so different from that of the reference run and the preceding technological runs, it is important to examine the policy changes implicit in this run in detail. First, it is assumed that advances in recycling and other resource-conserving technologies tend to decrease per capita resource usage at 4 percent per year. This implies that, if population and industrial output per capita remain constant, resource usage will be halved in approximately 17 years, divided by four after 34 years, and so on. Even though the growth in industrial output per capita tends to increase per capita resource usage, the exponential increase in recycling technologies assumed in the run implies that by the year 2100 each person will be consuming less than one-twentieth of the resources he used in 1970, all

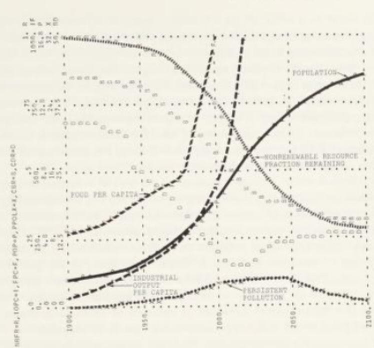

Figure 7-23 Run 7-18: exponential changes in technology

Here it is assumed that exponentially increasing technologies are able to postpone indefinitely the effects of the constraints to growth, as modeled in World3, at no cost and with no delays in development and implementation. The improved technologies tend to reduce per capita resource usage and pollution generation per unit of agricultural and industrial output at 4 percent per year after 1975. At the same time, land yields tend to increase at 4 percent per year, with no upper limit and with practically no adverse side effects such as land erosion. Although industrialization grows exponentially, the rate of removal of land for urban-industrial use decreases to zero by the year 2000. Finally, air pollution is assumed to have no adverse effects on land yield. Under these assumptions, population reaches 14 billion people in the year 2100 and continues to grow (though at a slow rate of 0.6 percent per year). Food is in abundance throughout the run, resource usage declines to zero as fewer resources are needed to sustain output, and industrial output per capita IOPC continues to grow indefinitely.

at no additional costs of energy, land, or any other physical factor. Under these assumptions, although the industrial capital stock has skyrocketed by 2100, the overall annual rate of nonrenewable resource usage *decreases* to less than one-fourth of its 1970 value by that year. Presumably this capital stock is primarily composed of renewable resources, as are the goods it manufactures, and presumably there are no limits to the rate of use of these renewable resources.

Similar assumptions were made in the agriculture and pollution sectors. Run 7-18 assumes that advances in land yield technologies increase land yields exponentially at 4 percent per year with no cost and no upper limit, and that virtually no