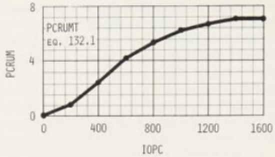

Figure 6-12 The relationship assumed, in Chapter 5, to exist between industrial output per capita and the annual per capita resource utilization.

and the toxicity indices of the two societies are equal, then the persistent pollution generation in the first society will be greater than that in the second.

While it is apparent that the industrial materials toxicity index IMTI, the industrial materials emission factor IMEF, and the fraction of resources that are persistent materials FRPM would have different values in industrialized and in agrarian societies, the lack of data, the long time horizon of the model, and their aggregated nature make it impossible to assign precise numerical values to the three parameters with great confidence. The following discussion thus aims primarily to provide an operational definition of the three factors in the equation defining persistent pollution generation from industrial output PPGIO and to illustrate the general considerations upon which their values depend. The discussion does not validate the set of exact numbers used for these three factors in the standard version of World3 model, but it does serve to establish the approximate magnitude of the real-world values.

To estimate the fraction of resources that is in the form of persistent materials FRPM, one might calculate the total weight of all materials produced in one year and then determine the relative fraction of the total that is composed of persistent materials. This calculation would require an analysis both of standard commodity production data and of those materials that are produced inadvertently. For example, the production of beryllium and other by-products in the smelting of metals is not included in published commodity production data. These by-products can be significant in absolute terms. For example, the mercury added each year to the environment through the combustion of fossil fuels is about 20 percent of the amount deliberately mined (Anderson et al. 1973).

Estimates of FRPM must also be based upon a consideration of the final chemical form of the resources consumed. For example, most petroleum is burned and produces only thermal energy and rather short-lived air pollutants. However, some petroleum is converted to chemical forms like PCBs and phenols that qualify as persistent materials. The U.S. refinery output in 1969 was about 1.4 billion barrels. About 98 million barrels, or 2 percent, of this output was in the form of petrochemical feedstocks that were converted ultimately into a wide variety of organic chemicals (Census 1971, p. 656). Not all organic chemicals are persistent pollutants, but some

are among the most disruptive environmental contaminants. Nearly 100 percent of some materials, such as mercury, is consumed in a form that is a persistent material. Given the uncertainties in current data, no exhaustive analysis of final output streams is justified. We simply accepted 2 percent as a reasonable estimate of the fraction of all resources consumed today in forms that would be classified as persistent materials.

The industrial materials emission factor IMEF is an estimate of the fraction of all persistent materials mobilized by industrial activities that eventually enters the environment (excluding materials employed in agriculture). It includes materials released in all phases of resource use: mining, purification, transportation, production, use, disposal, and recycling. There are many intensive studies of the emissions associated with specific products and production processes, but few sources provide cross-sectional data. The most comprehensive information on current emissions is probably that in SCEP (1970, pp. 257–273) and Ridker (1972). However, neither source presents extensive projections of future emissions: Ridker provides estimates for only a limited number of materials in the United States for the year 2000; and SCEP simply states: "We were unable to find global estimates for the percentage of emissions controlled. There appear to be no general projections of industrial growth; therefore we have not estimated future emissions of pollutants" (SCEP 1970, p. 266.)

Here, again, illustrative examples may provide some idea of the relative magnitudes involved, but they cannot provide a definitive estimate of the global emissions as a fraction of all persistent materials currently used. In 1970 the global production of mercury from mines was about 284,000 flasks, or around 10,000 tons, a large amount of which ultimately entered the environment. Oil may contain on the average about one ppm by weight of mercury. Thus the global production of oil in 1970 would have released about 1,800 tons of mercury into the environment through combustion. In the United States, 20 percent of the annual consumption of lead is employed in gasoline (Moulds 1972, p. 673). Virtually all of that lead eventually enters the environment. In World3 we estimated the industrial material emission factor IMEF to be 10 percent. This appears to be a conservative estimate of the fraction of persistent materials that eventually escapes to the environment.

The industrial materials toxicity index IMTI is the most difficult of the three factors to define operationally. It expresses the biological impact of a unit of persistent material from industrial sources. Its role is analogous to the agricultural material toxicity index, which expresses the harmful biological effects of one unit of persistent material released through agricultural activities. In World3 the index of pollution PPOLX, not the absolute level of pollution PPOL, is used to determine the magnitude of pollution damage in the agriculture and population sectors of the model. Thus the absolute magnitudes of the toxicity indices for the persistent materials in industry and agriculture are unimportant, but their size relative to each other should be estimated as carefully as the data warrant.

The toxic heavy metals appear primarily in industrial emissions. The case for their harmful impact on human health is well established: an extensive if popular survey of literature on these metals is provided in Tucker (1972), and general discus-