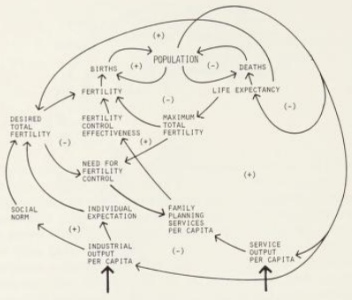

Figure 2-20 Feedback loops through fertility

influence the death rate through negative feedback loops also affect the birth rate through another (generally weaker) negative feedback loop.

The desired total fertility is involved in three feedback loops, two of them positive and one negative. The negative loop operates through the individual's assessment of the resources available for child-rearing. A population increase has a negative effect on industrial output per capita (all else being equal): as the growth rate of industrial output per capita decreases, the individual expectation of future family resources decreases, and desired total fertility decreases; a lower desired fertility leads to lower fertility, lower birth rate, and thus a lower rate of population increase.

This negative loop is counteracted by a positive loop that expresses the response of the social fertility norm to changing industrialization. A population increase causes a decrease in industrial output per capita, which after a long delay leads to a higher social norm with regard to family size. The higher norm then feeds back to increase the birth rate and the rate of population growth. The time delays in the two loops through industrial output per capita are quite different, and the relative strengths of the two loops are also very different at different levels of industrialization. Thus the model does not generate any simple response of desired family size to industrialization. The response can be positive, negative, or zero, depending on the growth pattern of the economic sectors.

Another positive feedback loop involving desired total fertility operates through life expectancy. This relationship expresses the hypothesis that families compensate for high mortality rates by purposely bearing more children than they actually desire. A population that perceives a high mortality rate among its children may desire to increase its fertility through this loop, but at the same time the poor health conditions that led to that high mortality may limit the possible fertility rate through the maximum total fertility loop.

The final causal loops in the population sector regulate fertility control effectiveness. This factor is increased by family planning services per capita in a positive feedback loop. A population increase leads to lower service output per capita, lower family planning services per capita, lower fertility control effectiveness, higher fertility, and thus a further population increase. All the loops, both positive and negative, influencing maximum and desired total fertility also affect fertility control effectiveness through the need for fertility control. (The need for fertility control is defined as the difference between maximum and desired fertility.)

There are several direct links between mortality and fertility in this model, and both respond independently to the economic and social factors generated in other sectors of the model. Thus many different mortality-fertility combinations may be generated, depending on the development of these outside factors. The model assumptions are not limited to the Malthusian hypothesis that population will automatically increase to its ultimate limit, at which point the death rate will rise to equal the birth rate. Neither do they automatically reflect the modern optimistic hypothesis that economic development will bring about a global demographic transition so that the birth rate will fall to equal the death rate. As we shall demonstrate in section 2.6, under appropriate external conditions the model system can exhibit either of these behavior modes, as well as other modes intermediate between the two extremes. A better expression of the basic philosophy incorporated in the feedback loops of the population sector is the "theory of demographic regulation" as described by Donald Bogue:

> Every society tends to keep its vital processes in a state of balance such that population will replenish losses from death and grow to an extent deemed desirable by collective norms. . . . These norms are not explicit opinions about desired population size or the optimum rate of growth. Instead, they are opinions concerning what constitutes the ideal size of completed family, or the number of surviving children a couple ought to have when it reaches the end of the reproductive period . . . . These norms are flexible and readjust . . . to changes in the ability of the economy to support population. [Bogue 1969, pp. 51–52]

2.5 DESCRIPTION OF EQUATIONS

A simplified DYNAMO flow diagram of the World3 population sector is shown in Figure 2-21. It represents a one-level population model with no disaggregation by age. For purposes of clarity, our discussion of the quantitative assumptions in the population sector begins with this simplest population model, which emphasizes the external rather than the demographic determinants of birth and death rates. At the end of this section we show how the single population level can be replaced by a four-level or a fifteen-level age-disaggregated representation, which more accurately expresses the demographic determinants of population dynamics.