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The Limits to Growth

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The overwhelming growth in world population caused by the positive birth-rate loop is a recent phenomenon, a result of mankind's very successful reduction of worldwide mortality. The controlling negative feedback loop has been weakened, allowing the positive loop to operate virtually without constraint. There are only two ways to restore the resulting imbalance. Either the birth rate must be brought down to equal the new, lower death rate, or the death rate must rise again. All of the "natural" constraints to population growth operate in the second way—they raise the death rate. Any society wishing to avoid that result must take deliberate action to control the positive feedback loop—to reduce the birth rate.

In a dynamic model it is a simple matter to counteract runaway positive feedback loops. For the moment let us suspend the requirement of political feasibility and use the model to test the physical, if not the social, implications of limiting population growth. We need only add to the model one more causal loop, connecting the birth rate and the death rate. In other words, we require that the number of babies born each year be equal to the expected number of deaths in the population that year. Thus the positive and negative feedback loops are exactly balanced. As the death rate decreases, because of better food and medical care, the birth rate will decrease simultaneously.

Such a requirement, which is as mathematically simple as it is socially complicated, is for our purposes an experimental device, not necessarily a political recommendation.[1] The result of inserting this policy into the model in 1975 is shown in figure 44.

In figure 44 the positive feedback loop of population growth is effectively balanced, and population remains constant. At first the birth and death rates

Donella H. Meadows, Jorgen Randers, and Dennis L. Meadows for the Club of Rome. 1972. *The limits to growth: A report for the Club of Rome's project on the predicament of mankind*, 158–175. New York: Universe Books.

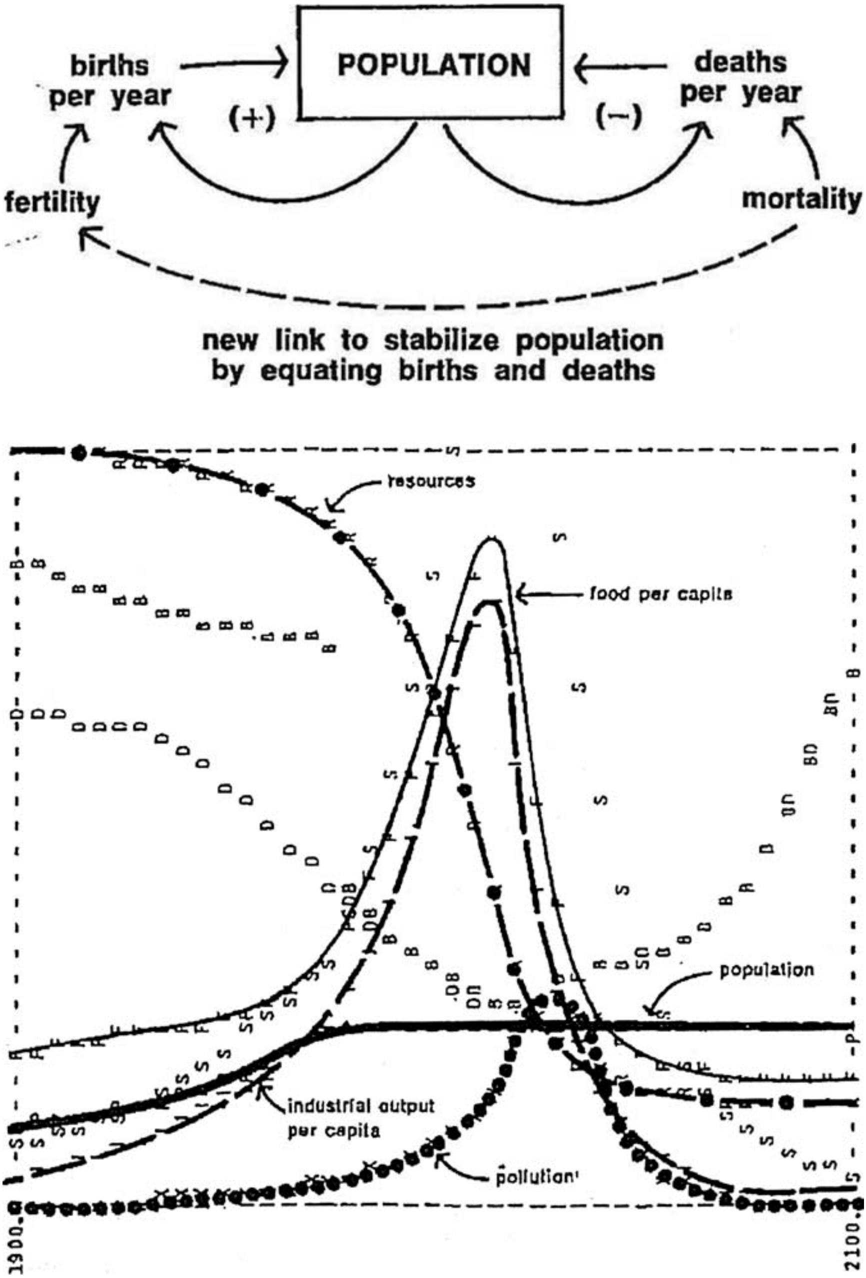


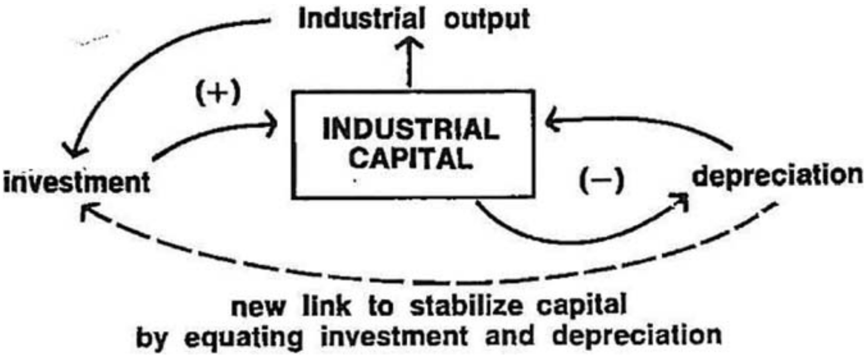
Figure 44. World Model with Stabilized Population. In this computer run conditions in the model system are identical to those in the standard run (figure 35), except that population is held constant after 1975 by equating the birth rate with the death rate. The remaining unrestricted positive feedback loop in the system, involving industrial capital, continues to generate exponential growth of industrial output, food, and services per capita. Eventual depletion of nonrenewable resources brings a sudden collapse of the industrial system.

are low. But there is still one unchecked positive feedback loop operating in the model—the one governing the growth of industrial capital. The gain around that loop increases when population is stabilized, resulting in a very rapid growth of income, food, and services per capita. That growth is soon stopped, however, by depletion of nonrenewable resources. The death rate then rises, but total population does not decline because of our requirement that birth rate equal death rate (clearly unrealistic here).

Apparently, if we want a stable system, it is not desirable to let even one of the two critical positive feedback loops generate uncontrolled growth. Stabilizing population alone is not sufficient to prevent overshoot and collapse; a similar run with constant capital and rising population shows that stabilizing capital alone is also not sufficient. What happens if we bring *both* positive feedback loops under control simultaneously? We can stabilize the capital stock in the model by requiring that the investment rate equal the depreciation rate, with an additional model link exactly analogous to the population-stabilizing one.

The result of stopping population growth in 1975 and industrial capital growth in 1985 with no other changes is shown in figure 45. (Capital was allowed to grow until 1985 to raise slightly the average material standard of living.) In this run the severe overshoot and collapse of figure 44 are prevented. Population and capital reach constant values at a relatively high level of food, industrial output, and services per person. Eventually, however, resource shortages reduce industrial output and the temporarily stable state degenerates.

What model assumptions will give us a combination of a decent living standard with somewhat greater stability than that attained in figure 45? We can improve the model behavior greatly by combining technological changes with value changes that reduce the growth tendencies of the system. Different combinations of such policies give us a series of computer outputs that represent a system with



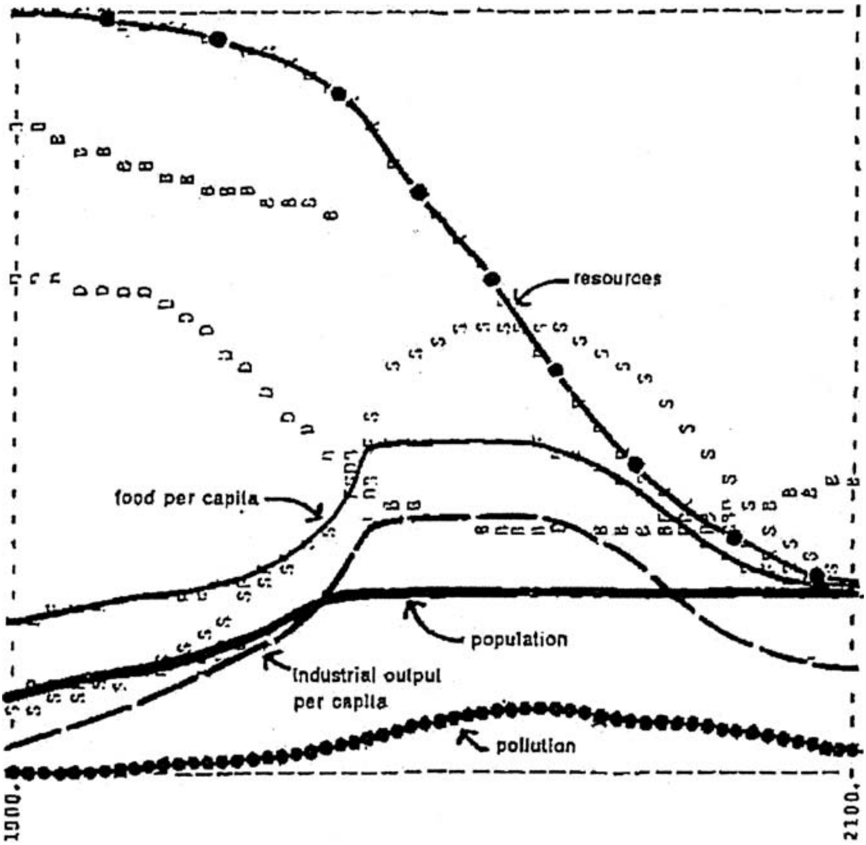


Figure 45. World Model with Stabilized Population and Capital. Restriction of capital growth, by requiring that capital investment equal depreciation, is added to the population stabilization policy of figure 44. Now that exponential growth is halted, a temporary stable state is attained. Levels of population and capital in this state are sufficiently high to deplete resources rapidly, however, since no resource-conserving technologies have been assumed. As the resource base declines, industrial output decreases. Although the capital base is maintained at the same level, efficiency of capital goes down since more capital must be devoted to obtaining resources than to producing usable output.

reasonably high values of industrial output per capita and with long-term stability. One example of such an output is shown in figure 46.

The policies that produced the behavior shown in figure 46 are:

1. Population is stabilized by setting the birth rate equal to the death rate in 1975. Industrial capital is allowed to increase naturally until

1990, after which it, too, is stabilized, by setting the investment rate equal to the depreciation rate.

2. To avoid a nonrenewable resource shortage such as that shown in figure 45, resource consumption per unit of industrial output is reduced to one-fourth of its 1970 value. (This and the following five policies are introduced in 1975.)
3. To further reduce resource depletion and pollution, the economic preferences of society are shifted more toward services such as education and health facilities and less toward factory-produced material goods. (This change is made through the relationship giving "indicated" or "desired" services per capita as a function of rising income.)
4. Pollution generation per unit of industrial and agricultural output is reduced to one-fourth of its 1970 value.
5. Since the above policies alone would result in a rather low value of food per capita, some people would still be malnourished if the traditional inequalities of distribution persist. To avoid this situation, high value is placed on producing sufficient food for *all* people. Capital is therefore diverted to food production even if such an investment would be considered "uneconomic." (This change is carried out through the "indicated" food per capita relationship.)
6. This emphasis on highly capitalized agriculture, while necessary to produce enough food, would lead to rapid soil erosion and depletion of soil fertility, destroying long-term stability in the agricultural sector. Therefore the use of agricultural capital has been altered to make soil enrichment and preservation a high priority. This policy implies, for example, use of capital to compost urban organic wastes and return them to the land (a practice that also reduces pollution.)
7. The drains on industrial capital for higher services and food production and for resource recycling and pollution control under the above six conditions would lead to a low final level of industrial capital stock. To counteract this effect, the average lifetime of industrial capital is increased, implying better design for durability and repair and less discarding because of obsolescence. This policy also tends to reduce resource depletion and pollution.

In figure 46 the stable world population is only slightly larger than the population today. There is more than twice as much food per person as the average value in 1970, and world average lifetime is nearly 70 years. The average industrial output per capita is well above today's level, and services per capita have tripled. Total average income per capita (industrial output, food, and services combined)

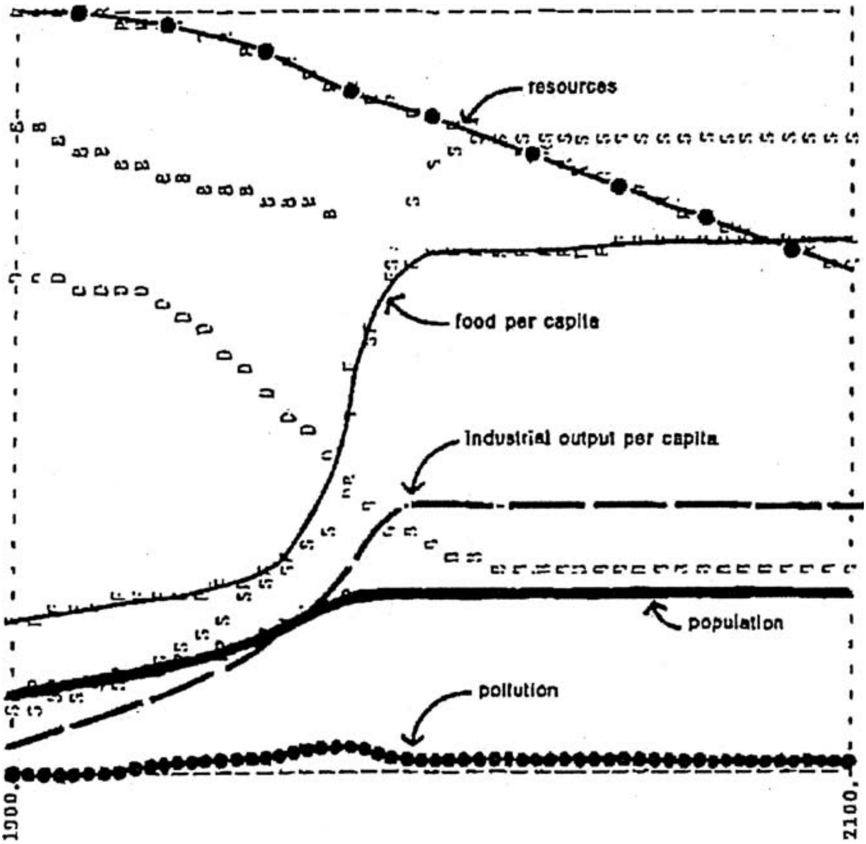


Figure 46. Stabilized World Model I. Technological policies are added to the growth-regulating policies of the previous run to produce an equilibrium state sustainable far into the future. Technological policies include resource recycling, pollution control devices, increased lifetime of all forms of capital, and methods to restore eroded and infertile soil. Value changes include increased emphasis on food and services rather than on industrial production. As in figure 45, births are set equal to deaths and industrial capital investment equal to capital depreciation. Equilibrium value of industrial output per capita is three times the 1970 world average.

is about $1,800. This value is about half the present average US income, equal to the present average European income, and three times the present average world income. Resources are still being gradually depleted, as they must be under any realistic assumption, but the rate of depletion is so slow that there is time for technology and industry to adjust to changes in resource availability.

The numerical constants that characterize this model run are not the only ones that would produce a stable system. Other people or societies might resolve the various trade-offs differently, putting more or less emphasis on services or food or pollution or material income. This example is included merely as an illustration of the levels of population and capital that are *physically maintainable* on the earth, under the most optimistic assumptions. The model cannot tell us how to attain these levels. It can only indicate a set of mutually consistent goals that are attainable.

Now let us go back at least in the general direction of the real world and relax our most unrealistic assumptions—that we can suddenly and absolutely stabilize population and capital. Suppose we retain the last six of the seven policy changes that produced figure 46, but replace the first policy, beginning in 1975, with the following:

1. The population has access to 100 percent effective birth control.
2. The average desired family size is two children.
3. The economic system endeavors to maintain average industrial output per capita at about the 1975 level. Excess industrial capability is employed for producing consumption goods rather than increasing the industrial capital investment rate above the depreciation rate.

The model behavior that results from this change is shown in figure 47. Now the delays in the system allow population to grow much larger than it did in figure 46. As a consequence, material goods, food, and services per capita remain lower than in previous runs (but still higher than they are on a world average today).

We do not suppose that any single one of the policies necessary to attain system stability in the model can or should be suddenly introduced in the world by 1975. A society choosing stability as a goal certainly must approach that goal gradually. It is important to realize, however, that the longer exponential growth is allowed to continue, the fewer possibilities remain for the final stable state. Figure 48 shows the result of waiting until the year 2000 to institute the same policies that were instituted in 1975 in figure 47.

In figure 48 both population and industrial output per capita reach much higher values than in figure 47. As a result pollution builds to a higher level and resources are severely depleted, in spite of the resource-saving policies finally introduced. In fact, during the 25-year delay (from 1975 to 2000) in instituting the stabilizing policies, resource consumption is about equal to the total 125-year consumption from 1975 to 2100 of figure 47.

Many people will think that the changes we have introduced into the model to avoid the growth-and-collapse behavior mode are not only impossible, but un-

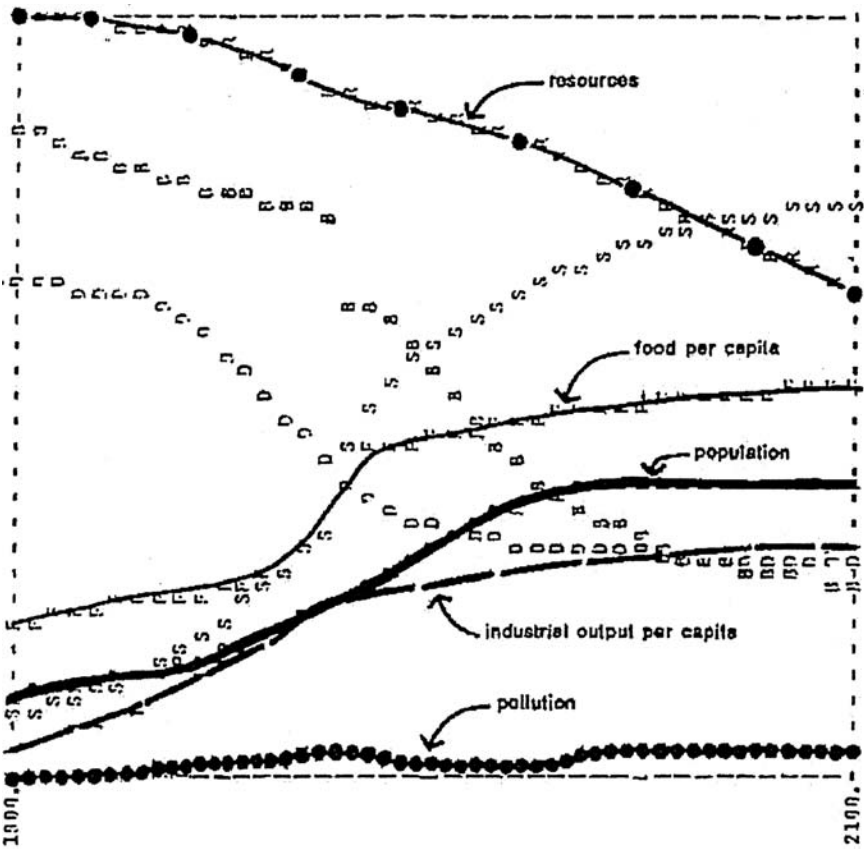


Figure 47. Stabilized World Model II. If the strict restrictions on growth of the previous run are removed, and population and capital are regulated within the natural delays of the system, the equilibrium level of population is higher and the level of industrial output per capita is lower than in figure 46. Here it is assume that perfectly effective birth control and an average desired family size of two children are achieved by 1975. The birth rate only slowly approaches the death rate because of delays inherent in the age structure of the population.

pleasant, dangerous, even disastrous in themselves. Such policies as reducing the birth rate and diverting capital from production of material goods, by whatever means they might be implemented, seem unnatural and unimaginable, because they have not, in most people's experience, been tried, or even seriously suggested. Indeed there would be little point even in discussing such fundamental changes in the functioning of modern society if we felt that the present pattern of unrestricted growth were sustainable into the future. All the evidence available

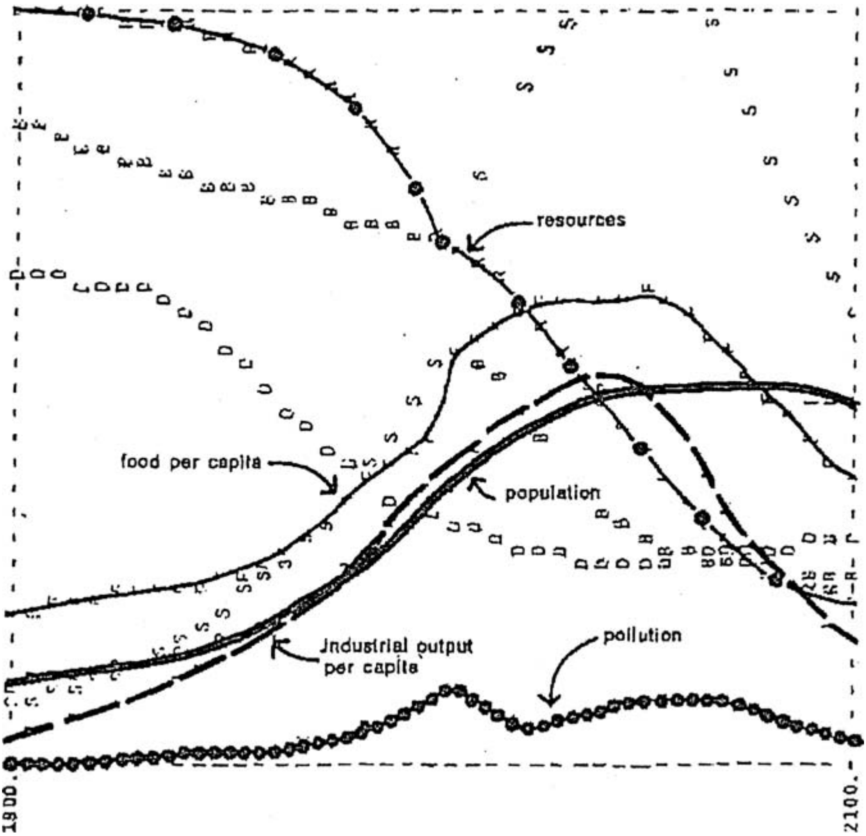


Figure 48. World Model with Stabilizing Policies Introduced in the Year 2000. If all the policies instituted in 1975 in the previous figure are delayed until the year 2000, the equilibrium state is no longer sustainable. Population and industrial capital reach levels high enough to create food and resource shortages before the year 2100.

to us, however, suggests that of the three alternatives—unrestricted growth, a self-imposed limitation to growth, or a nature-imposed limitation to growth—only the last two are actually possible.

Accepting the nature-imposed limits to growth requires no more effort than letting things take their course and waiting to see what will happen. The most probable result of that decision, as we have tried to show here, will be an uncontrollable decrease in population and capital. The real meaning of such a collapse is difficult to imagine because it might take so many different forms. It might occur at different times in different parts of the world, or it might be worldwide. It could be sudden or gradual. If the limit first reached were that of food production, the nonindustrialized countries would suffer the major population decrease. If the first limit were imposed by exhaustion of nonrenewable resources, the industrialized countries would be most affected. It might be that the collapse would leave the earth with its carrying capacity for animal and plant life undiminished, or it might be that the carrying capacity would be reduced or destroyed. Certainly whatever fraction of the human population remained at the end of the process would have very little left with which to build a new society in any form we can now envision.

Achieving a self-imposed limitation to growth would require much effort. It would involve learning to do many things in new ways. It would tax the ingenuity, the flexibility, and the self-discipline of the human race. Bringing a deliberate, controlled end to growth is a tremendous challenge, not easily met. Would the final result be worth the effort? What would humanity gain by such a transition, and what would it lose?

. . .

The Equilibrium State

We are by no means the first people in man's written history to propose some sort of nongrowing state for human society. A number of philosophers, economists, and biologists have discussed such a state and called it by many different names, with as many different meanings.

We have, after much discussion, decided to call the state of constant population and capital, shown in figures 46 and 47, by the term "equilibrium." Equilibrium means a state of balance or equality between opposing forces. In the dynamic terms of the world model, the opposing forces are those causing population and capital stock to increase (high desired family size, low birth control effectiveness, high rate of capital investment) and those causing population and capital stock to decrease (lack of food, pollution, high rate of depreciation or obsolescence). The word "capital" should be understood to mean service, industrial, and agricultural capital combined. *Thus the most basic definition of the state of global equilibrium is that population and capital are essentially stable, with the forces tending to increase or decrease them in a carefully controlled balance.*

There is much room for variation within that definition. We have only specified that the stocks of capital and population remain constant, but they might theoretically be constant at a high level or a low level—or one might be high and the other low. A tank of water can be maintained at a given level with a fast inflow and outflow of water or with a slow trickle in and out. If the flow is fast, the average drop of water will spend less time in the tank than if the flow is slow. Similarly, a stable population of any size can be achieved with either high, equal birth and death rates (short average lifetime) or low, equal birth and death rates (long average lifetime). A stock of capital can be maintained with high investment and depreciation rates or low investment and depreciation rates. Any combination of these possibilities would fit into our basic definition of global equilibrium.

What criteria can be used to choose among the many options available in the equilibrium state? The dynamic interactions in the world system indicate that the first decision that must be made concerns time. *How long should the equilibrium state exist?* If society is only interested in a time span of 6 months or a year, the world model indicates that almost any level of population and capital could be maintained. If the time horizon is extended to 20 or 50 years, the options are greatly reduced, since the rates and levels must be adjusted to ensure that the capital investment rate will not be limited by resource availability during that time span, or that the death rate will not be uncontrollably influenced by pollution or food shortage. The longer a society prefers to maintain the state of equilibrium, the lower the rates and levels must be.

At the limit, of course, no population or capital level can be maintained forever, but that limit is very far away in time if resources are managed wisely and if there is a sufficiently long time horizon in planning. Let us take as a reasonable time horizon the expected lifetime of a child born into the world tomorrow—70 years if proper food and medical care are supplied. Since most people spend a large part of their time and energy raising children, they might choose as a minimum goal that the society left to those children can be maintained for the full span of the children's lives.

If society's time horizon is as long as 70 years, the permissible population and capital levels may not be too different from those existing today, as indicated by the equilibrium run in figure 47 (which is, of course, only one of several possibilities). The rates would be considerably different from those of today, however. Any society would undoubtedly prefer that the death rate be low rather than high, since a long, healthy life seems to be a universal human desire. To maintain equilibrium with long life expectancy, the birth rate then must also be low. It would be best, too, if the capital investment and depreciation rates were low, because the lower they are, the less resource depletion and pollution there will be. Keeping depletion and pollution to a minimum could either increase the maximum size of the population and capital levels or increase the length of time the equilibrium state could be maintained, depending on which goal the society as a whole has preferred.

By choosing a fairly long time horizon for its existence, and a long average lifetime as a desirable goal, we have now arrived at a minimum set of requirements for the state of global equilibrium. They are:

1. *The capital plant and the population are constant in size*. The birth rate equals the death rate and the capital investment rate equals the depreciation rate.
2. *All input and output rates—births, deaths, investments, and depreciation are kept to a minimum.*
3. *The levels of capital and population and the ratio of the two are set in accordance with the values of the society*. They may be deliberately revised and slowly adjusted as the advance of technology creates new options.

An equilibrium defined in this way does not mean stagnation. Within the first two guidelines above, corporations could expand or fail, local populations could increase or decrease, income could be more or less evenly distributed. Technological advance would permit the services provided by a constant stock of capital to increase slowly. Within the third guideline, any country could change its average standard of living by altering the balance between its population and its capital. Furthermore, a society could adjust to changing internal or external factors by raising or lowering the population or capital stocks, or both, slowly and in a controlled fashion, with a predetermined goal in mind. The three points above define a *dynamic* equilibrium, which need not and probably would not “freeze” the world into the population-capital configuration that happens to exist at the present time. The object in accepting the above three statements is to create freedom for society, not to impose a straitjacket.

What would life be like in such an equilibrium state? Would innovation be stifled? Would society be locked into the patterns of inequality and injustice we see in the world today? Discussion of these questions must proceed on the basis of mental models, for there is no formal model of social conditions in the equilibrium state. No one can predict what sort of institutions mankind might develop under these new conditions. There is, of course, no guarantee that the new society would be much better or even much different from that which exists today. It seems possible, however, that a society released from struggling with the many problems caused by growth may have more energy and ingenuity available for solving other problems. In fact, we believe . . . that the evolution of a society that favors innovation and technological development, a society based on equality and justice, is far more likely to evolve in a state of global equilibrium than it is in the state of growth we are experiencing today.

Note

1. This suggestion for stabilizing population was originally proposed by Kenneth E. Boulding in *The meaning of the 20th century* (New York: Harper and Row, 1964).

Commentary

Donella H. Meadows, Jorgen Randers, and Dennis L. Meadows for the Club of Rome, *The Limits to Growth* (1972)

MICHAEL EGAN

The Limits to Growth holds an important place both in environmental prediction and in global environmental history. It constitutes a methodological sea change in the history of engaging with future natures. Through the use of computer modeling and the adoption of the then recently conceived field of system dynamics, the book forecasts a variety of economic collapse scenarios should production and consumption patterns continue to grow exponentially. During a period in which gloomy predictions of environmental futures were fairly commonplace, the study—a report produced for the Club of Rome by a team headed by Donella Meadows—offered a unique approach that they interpreted as a global *problematique*. For its authors, system dynamics represented a portal through which society could better understand the origins, significance, and interrelationships between its myriad components. The group's use of computers to process data and model futures heralded a new era of large-scale and complex environmental prediction. *The Limits to Growth* transformed the nature of the debate surrounding the earth's carrying capacity and anticipating global trends in population, economics, and the environment.

The central message of *The Limits to Growth* was that the human ecological footprint could not continue to grow at the same pace experienced in the twentieth century. Within the next century, humanity's ecological footprint would overshoot the Earth's carrying capacity. The book's introduction boldly stated the group's findings:

> 1. If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
> 2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize their individual human potential.

> 3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success. (Meadows et al. 1972, 23–24)

While *The Limits to Growth* was not unique in its bleak forecast of humanity's environmental future, the amount of data it gathered for the analysis, its international collaborative nature, and its novel approach with computer modeling brought considerable attention to its findings. It was published in thirty-seven languages and sold twelve million copies worldwide.

The Club of Rome was formed in 1968 at the behest of Dr. Aurelio Peccei. Its task was to develop a thorough analysis of "the present and future predicament of man" (ibid., 9). The Club of Rome was not a formal organization, but rather an independent, informal, and international body. It comprised an "invisible college" of experts in policy, economics, and the natural and social sciences. By 1970, it had seventy-five members from twenty-five countries and had identified sixty-six "Continuous Critical Problems" that together constituted a focus for the predicament they sought to resolve. Confronted with a seemingly inchoate list of social, economic, political, and environmental issues—poverty, war, terrorism, pollution, crime, racism, resource depletion, economic instability, drug addiction— American computer engineer Jay Wright Forrester, at a Club meeting in Bern, Switzerland, suggested that *growth* could be a unifying thread among the disparate problems.

Forrester had worked on aircraft flight simulators immediately after World War II and played an important role in developing the Whirlwind digital computer. Forrester was an inveterate problem-solver; by 1956, he left computer development and turned his attention to building the Sloan School of Management at the Massachusetts Institute of Technology (MIT), where he began to think more explicitly about systems. Whereas simple models frequently consisted of closely related causes and effects, more complex models put greater distance and time between cause and effect, making it much more difficult to identify or predict the defining relationships and realize sound solutions to specific problems. Forrester's efforts to demystify the inherent complexity in multifaceted systems led him to devise a mathematical modeling technique, data for which could be fed into early computer systems. In essence, this modeling technique was the heart of system dynamics, a method for understanding the dynamic behavior of complex systems. It used a holistic analysis of the system and the interactions between its elements, rather than a concentration on the workings of its individual components.

Spurred by Forrester's assertions that system dynamics was a useful tool for uncovering the root causes of global problems, the Club of Rome initiated a first phase of the Project on the Predicament of Mankind to delve into resource and environmental problems. The group was headed by Dennis Meadows, a graduate student of Forrester's (Dennis's wife, Donella Meadows, was the lead author of the study). The Project on the Predicament of Mankind set the research parameters for *The Limits to Growth* and was designed to address a series of interrelated global problems—namely, "poverty in the midst of plenty; degradation of the environment; loss of faith in institutions; uncontrolled urban spread; insecurity of employment; alienation of youth; rejection of traditional values; and inflation and other monetary and economic disruptions" (ibid., 10). The first (research) phase—the basis of *The Limits to Growth*—involved a concerted examination of five specific factors that dictate the boundaries of life on the planet, and thereby determine and limit growth: population, agricultural production, natural resources, industrial production, and pollution. Each of these factors was universal, and all possessed interacting social, technical, economic, and political components ideal for analysis in terms of system dynamics.

Building on Forrester's earlier efforts, the MIT team produced the global computer model World3 in order to chart the dynamic implications of growth. Assembling indexes to predict population growth, resource consumption, and pollution, the authors recognized that the rates of change were growing exponentially but at different rates, and that they would need to factor in the implications of their changing interrelationships over time in order to determine long-term trends. At the heart of this problem—and, indeed, at the heart of system dynamics—lies the importance of the feedback loop, or "vicious circle," which is a closed path that connects an action to its disturbance on surrounding conditions. This in turn sets the tone for subsequent action. In this mode of analysis, which allowed for the computation of vastly complex arrays of data, systems dynamics adopted the (almost ecological) notion that the whole system was greater than the sum of its parts. Several decades later, *The Limits to Growth* remains one of the best-known examples of a study employing system dynamics.

Where method and message warned against continued growth, *The Limits to Growth* emphasized equilibrium as a desirable end stage. This served as one of many catalysts at the beginning of the 1970s for the new global movement for environmental sustainability. While sustainability is often linked to the 1972 United Nations Conference on Humans and the Environment in Stockholm—and the subsequent Brundtland Commission report, *Our Common Future*, of 1987, seeds of its genesis are present in *The Limits to Growth*'s concluding observations, reproduced here. In effect, *The Limits to Growth* began a conversation that evolved into a complex debate about the merits of steady-state economics and the biophysical limits of economic growth. In 1972, this was fresh, provocative, and controversial—its dependence on computer modeling, even more so.

Further Reading

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