LIMITS TO GROWTH THROUGH FUNCTIONAL SPECIALIZATION IN A CLOSED SYSTEM[1]

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TO ADAM SMITH, FUNCTIONAL SPECIALIZATION SUPPORTED BY INcreasing capital accumulation was the engine of long-term economic growth. Although the *Wealth of Nations* provided several possible leads as to the limits of growth, i.e., resource limitation, declining profit, lack of technological improvement, artificial barriers to factor mobility and competition, and limited market, Smith was evidently more concerned about what promoted growth. Smith's famous statement that division of labor was limited by the extent of the market should not, therefore, be construed to mean that he believed limited markets were the most serious detriment to economic growth.

The above-mentioned restraints on economic growth have been discussed at length by other writers. In particular, the notion that dwindling stocks of natural resources inevitably limit growth has been a popular thesis during the past decade (Meadows et al., 1972). Although this paper deals with resource utilization and its relationship to the growth process, it does not address simply the question of resource stock depletion.

In this paper, the economy is viewed as a subsystem of a larger whole that includes, for example, the social structure, the ecological system and so forth. Within this larger system, the values of the subsystems' variables must be compatible with those of the whole in order to achieve viability and stability. The growth of the economic system essentially feeds on resources diverted from other subsystems that it regards as *slack*. This slack consists of material resources as well as the capacity of other subsystems to absorb externalities generated by the growth of the economic system. The thesis of this paper is that the ultimate limit to economic growth may well be reached when the growth process reduces and ultimately eliminates this slack. While this process is attributable to resource *scarcity*, it does not depend solely or even importantly on the notion of resource stock depletion. No harm is done to the following analysis by assuming that all conventional resources are renewable or replaceable.

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This paper consists of two major sections. The first will deal with the notion of closed and open systems, how they relate to economic activity and economic policy formulation, and the nature of the growth process in closed versus open economic systems. In the second, the interaction between the growth process and the nature of functional specialization will be analyzed in the context of a simple visual model.

A SYSTEMS APPROACH TO THE ANALYSIS OF GROWTH

Closed and Open Systems and Economic Policy. In ecological literature, a closed system is understood as a system of interacting parts among which there is reciprocal exchange, for no one part experiences unilateral movement. In economic terms, this means that none of the variables may be viewed as only an output or an input. The output of one process is the input into another process, ultimately completing a "loop." A closed interaction loop can be illustrated by the cattle-manure-grass interaction loop on a fixed amount of pasture before the introduction of chemical fertilizers (see Figure 1). When the available resources are fully utilized under the existing technology, all variables in the loop are relevant and their values have to be determined simultaneously to achieve economy and stability (Margalef, 1968:1–25).

An open system, on the other hand, is understood as one with *some* of its parts not completely interacting, either because they do not by nature interact or because they do not interact at the limit of their operating capacity. The introduction of chemical fertilizers (or more generally fossil fuel subsidized inputs) into the above example adds an extra degree of freedom to an otherwise closed system. Under this new condition, the number of cattle can be increased independently of the amount of manure they produce. The independence between the chemical fertilizers and the number of cattle thus "opens up" the previously closed interaction loop as the amount of manure is no longer relevant to the production of cattle. In fact, manure is often treated as waste to be disposed of into the environment. The two situations are illustrated in Figures 1 and 2, respectively, the direction of arrows indicating flow from input to output.

While the notions of closed and open systems are useful abstractions, it is important to emphasize that they represent polar cases. As Boulding (1970) has indicated, it is difficult to conceive of a system that is perfectly closed, for if it did not least emit information we never would know of it. It follows that, if all systems are to some extent open, the *degree* of closedness (or openness) replaces the open-closed dichotomy as the relevant consideration. While the degree of openness may defy cardinal measurement, a system may be generally regarded as more open the more rapidly activity can flow through it without eliciting reaction from its subsystems (or the less reaction elicited for a given

FIGURE 1
Closed Loop

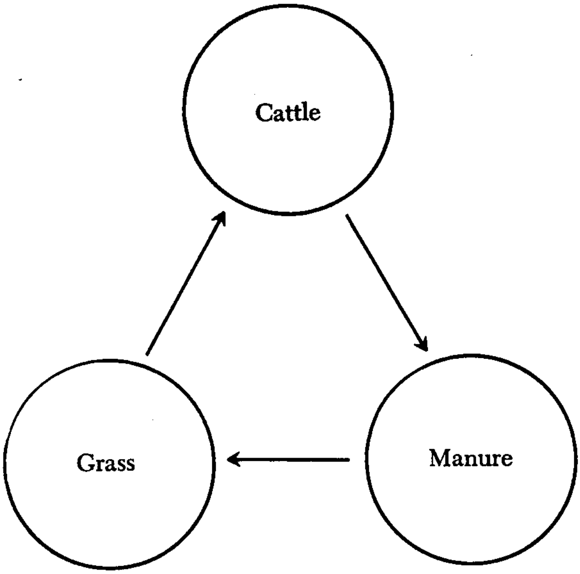
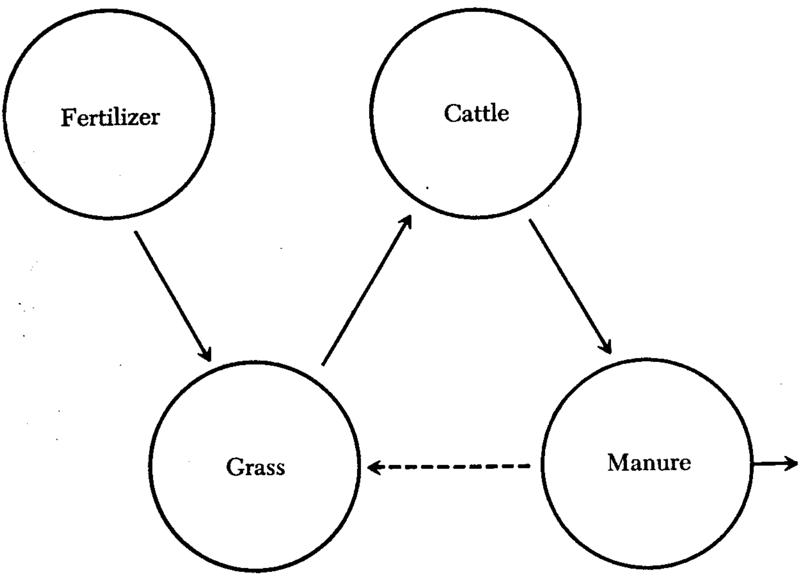


FIGURE 2
Open Loop



rate of throughput), and conversely. It is the relevance of this new variable, the degree of openness (or closedness) of a system, to the theory of economic policy formulation and to the growth process that is of concern here.

Economic policy formulation, or the carrying on of economic activity in general, is simplified by the classification of variables as relevant or irrelevant and the further delineation of relevant variables as targets or instruments (Tinbergen, 1970). Target variables are those whose values are deliberately chosen as ends in themselves; the values of instrumental variables are set in such a way as to achieve the target values, and those of irrelevant variables are residually determined. Such a classification scheme is helpful, however, only in the context of an open system. In a closed system, such as the cattle-manure-grass loop, all variables are relevant and the distinction between targets and instruments becomes hopelessly blurred. Ceteris paribus, the more open the system, the more variables may be regarded as irrelevant. The ability to treat some variables as irrelevant is important for purposes of policy formation, for, as Tinbergen (1970) has shown, target values can be freely chosen only if the number of targets does not exceed the number of instruments. As a relatively open system begins to close, the choice of relevant variables ceases to be a matter of analytical convenience as reactions from an increased number of subsystems force policy makers to treat more and more variables as targets. In turn, achieving basic goals becomes increasingly difficult until, at its limit, the system closes and no variables can be independently determined.

Although we are not treating systems as strictly open or closed, Tinbergen's classification scheme is nevertheless useful. Viewed from Tinbergen's analytical framework, functional specialization is open-system oriented. It is merely a process to increase the number of single purpose instruments[2] for specific targets so that the values of more targets can be freely chosen. In the context of Figure 1, cattle served as multiple purpose instruments, yielding both meat and fertilizer. In Figure 2, the system was opened up as the cattle became single purpose instruments. So long as the further creation of single purpose instruments is unconstrained, subsystems can continue to be viewed as open, and growth is not limited. However, the further creation of single purpose instruments involves a fundamental contradiction. On one hand, more *independent* decision units are created; on the other, external effects among these decision units become increasingly important. While functional specialization is being directed toward open-

[2] Single purpose instruments refer to those instruments that are designed to achieve specific targets in one subsystem. Their roles in other subsystems are merely incidental and in no way affect the performance of their designed roles. As such, they should be distinguished from specialists in a larger system with closed interaction loops in which all of the roles of the specialists are equally important for the performance of the system.

ing up interaction loops, it is simultaneously closing them as well as others. In the following section, the process will be examined in greater detail.

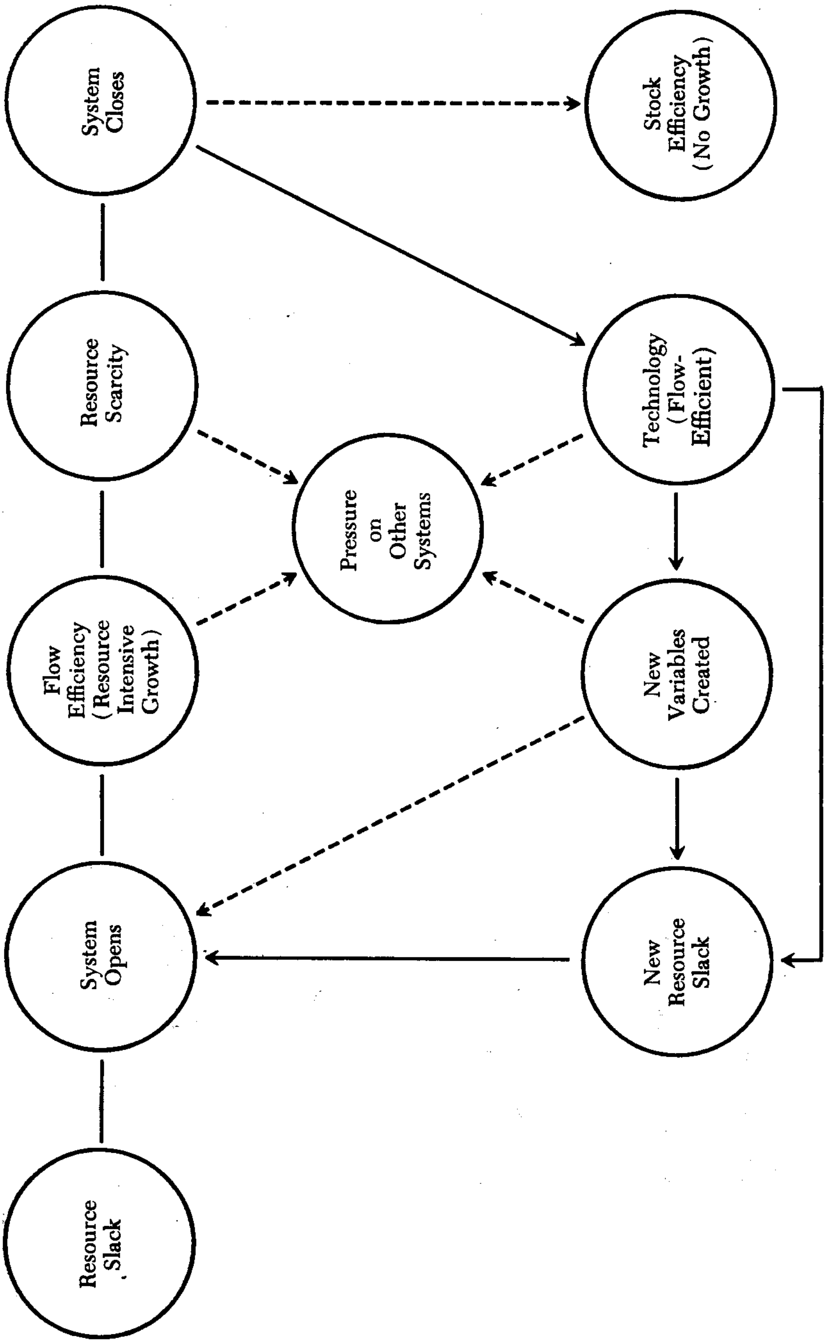
Growths, Technology, and Intersystem Spillovers. As noted above, a closed system in which slack for all resources has been used up by definition cannot grow. But since the existence and the quantity of slacks are technologically determined, a change in technology in an otherwise closed system will produce new slacks. These new slacks will open up the system and allow further growth to take place. The extent and the kind of growth will depend on the nature of the slacks (i.e., whether the resource is renewable or nonrenewable) and the nature of the technology that is used to exploit the slacks (i.e., whether it is open-system or closed-system oriented).

In terms of the first law of thermodynamics, growth in such a system must necessarily be growth of one part at the expense of the others. Since economic growth is a process in which the flow of resources through the economic domain is increased, this growth draws on slacks which exist either in the economic subsystem itself or in other subsystems. But its growth is always confined by a larger system within which all interactions must ultimately be closed. Therefore, as the economic system grows, fundamental change is taking place; slack is created in the economic subsystem through the diversion of resources from other subsystems.

Whenever significant resource slack exists, economic societies place little constraint on the use of that resource, whether the economy is market-oriented or controlled. Economic activity will be directed not toward conscientious management of the resource stock but toward maximization of resource flow, at least up to the extensive margin of that resource. More generally, if they are viewed as superabundant, a number of resources will all be "priced" at or near zero, and emphasis will be placed on what might be termed "flow efficiency" rather than "stock efficiency."[3] Output will be maximized, and the longer term effects on stocks will be ignored. This emphasis on flow efficiency is inherently (and rationally) resource intensive. Resource slack is exploited in order to make other, more limited resources more efficient in the short run. Because this growth process is resource intensive, however, ultimately the resource slack will be reduced and the system will tend to close. At this point, either emphasis must turn to stock efficiency or flow efficiency experts must devise ways to reopen the system through technological advances.

[3] As noted earlier, all resources may be assumed to be *renewable*. In this context, "stock efficiency," at least in a partial equilibrium, is achieved if the maximum sustainable flow of the resources is efficiently allocated among its competing uses. If resources are viewed as nonrenewable, stock efficiency would involve some (implicit or explicit) pricing mechanism to encompass depletion costs as well as extraction costs.

FIGURE 3
Resource Slack, Technology and System States



For convenience, the process described above is summarized in Figure 3. The top row of circles describes the economic process whereby resource slack enables the society to treat its economic system as open, and the resulting emphasis on flow efficiency that ultimately reduces that slack, causing the system to begin to close. The second row indicates the fundamental alternatives posed by closure of the system. Either society restructures its economy with emphasis on stock efficiency and no growth *or* restructures the economy with increasing emphasis an open-system specialization and flow-efficient technology. Flow-efficient technology must be designed to reopen the system, either through the creation of new variables (such as the chemical fertilizers in Figures 1 and 2) or through the development of new resources. In either case, however, the process whereby technology concentrates on opening up old feedback loops invariably exerts pressure on other subsystems.[4]

In more general terms, when functional specialization is open-system oriented, variables subsequently treated as irrelevant are not properly looped with the relevant variables. Moreover because the process becomes more complex, the loops among relevant variables often will be simplified as much as possible. As a result, those functions that have still not been taken over by specialized institutions tend to be relegated to the status of irrelevant variables. But the freedom of those specialized institutions to pursue their single purpose objectives involves the danger of conflicting objectives that cannot easily be resolved. In terms of Figure 3, the *capacity to bypass the resource restriction* imposed by the old interaction loops *does not eliminate the link* of those selected variables in the expanding subsystem to other variables in the larger interaction network. Setting the values for these selected variables residually determines the values of other variables no longer considered relevant to the new interaction loops. In short, the increasing complexity of the system, in terms of both more specialized decision-making entities and more specialized variables, breeds inconsistencies and incompatibility among the variables. Such incompatibility may develop not only between relevant and irrelevant variables but also among relevant variables.

The fact that feasible, or tolerance, regions even exist for the values

[4] Examples of such pressure are not difficult to uncover. In general, pressure might involve either quantitative or qualitative pollutants (Erhlich, et al., 1973:165), analogous to the overloading and shorting, respectively, of an electrical circuit. In terms of Figures 1 and 2, open-system functional specialization and the role of cattle as single purpose instruments caused an accumulation of manure, an overloading of the larger system by quantitative pollutants. But the introduction of new inputs into the ecosystem may also generate qualitative pollutants. DDT, for example, was introduced as a single purpose instrument to kill pests that feed on farm crops. As a synthesized substance, DDT adds a loose end to the closed-loop interaction system. Its harmful effects to the reproduction of many wild species, though "irrelevant" variables to the economic system, represent a case of short-circuiting.

of irrelevant variables is simply because these variables are classified as such only for the convenience of a given interaction loop. Actually, irrelevant variables of one interaction loop may be the target variables of another. Thus, the fact that targets are freely chosen only through the adjustment of "irrelevant" variables implies that the target values of some interaction loops are residually determined by those of other loops. If those residually determined values are not compatible with the operating capacity of their respective interaction loops, either their operating capacities must adjust or limits will be imposed on the expanding system. If their operating capacities are adjusted, these bottleneck irrelevant variables will be included in the set of relevant variables. If not, the capacity of the whole system to accommodate the extra degree of freedom introduced by technology will be limited because of the needs for the parts to be compatible with the whole in a viable closed system.

Incompatibility among the values of the relevant variables is equally restricting. Particularly when more and more variables are included in the set of relevant variables, the distinction between instruments and targets becomes increasingly hazy. As more complicated loops develop, formerly independent instruments lose their independence; the values they *can* assume come to depend on values of the old targets by virtue of new linkages. But a dependent instrument is simply a target, and a target whose value also determines the value of another target is an instrument. Their values must be simultaneously determined if they are to be compatible (although the absolute level of their simultaneously determined values can be set arbitrarily if the side effects of their value set on other subsystems do not in turn affect the production system), but there is no reliable mechanism to assume that they will in fact be compatible.[5]

Whether the problem is viewed as an incompatibility between relevant and irrelevant variables or as an incompatibility among relevant variables, however, the end result is the same. The order of the ex-

[5] In contrast, if the system were characterized by closed, mutually reinforced interaction loops, general order would be the result of systematic integration. No particular parts are specially charged with the role of integrating the system. For example, discussing an ideal low energy society, Cottrell (1955:238) has written: "If it were possible to extend the process of identification characteristic of experience in the family to include all producers and all consumers, the production unit would in every case be coexistensive and reciprocal with a consumer group. The problem of securing social coordination of production and consumption would then be solved. Morality would automatically assure that each would produce 'according to his need.' Ability and need would be socially defined, and socially created norms would be so related as to produce the choices necessary to secure the required repeated action. Since each individual would want to do what he had to do, nobody would have to be forced to do anything." See also Odum (1971:150–151,159) for a more conceptual discussion of mutual reinforcement among interaction loops and its importance to system viability.

panding subsystems depends on the existence of some general order in the larger system. Consequently, interaction loops, once considered independent and open, are forced to merge, either literally or through the internalization of external effects. Furthermore, the resultant larger system resembles the archetypal closed system more closely than did the smaller systems it subsumed. The "no growth" principles applicable to the purely closed system therefore become more relevant. Likewise, the cycle described in Figure 3 is intensified as the larger system first ignores the pressure it places on other systems, but which it ultimately must account for. The true limits to growth are reached when all slack in the system is exhausted. Inasmuch as the capacity of subsystems to absorb externalities is virtually equivalent to the availability of slack, it follows that an ever increasing necessity to internalize externalities would tend to indicate that slack is being depleted.

SUMMARY AND CONCLUSION

Functional specialization is Nature's way to an efficient utilization of energy and other resources. In the human society, this arrangement is justified by the law of comparative advantage. However, in a closed living system the extent of functional specialization is always limited by the flow of energy and material resources, and by the need for the parts to be compatible with the whole. The interrelatedness of the parts is manifested in the multifarious reinforcing interaction loops established among them for the sake of growth, economy and stability.

When the flow of energy and material resources is constant, the system than can adopt different states tends to adopt, after a time, the most stable and efficient of them. When the flow of energy and material resources is increasing, the subsystem that can rapidly use the additional resources will expand at the expense of the other subsystems. In order to do that, single purpose instruments that can take advantage of the more abundant energy supply are created. These single purpose instruments allow some targets within the expanding subsystem to be set independently of the resource-recycling capacity of the whole system. But the creation of these single purpose instruments in the expanding subsystem means that some formerly relevant targets are turned into irrelevant variables for that subsystem. And because new resources and processes are used, additional variables irrelevant to the expanding subsystem may also be created.

But these irrelevant variables are very relevant in the larger closed system. And since their values have been arbitrarily set by the expanding subsystem, they may not be compatible with the rest of the system. This results in overloading or short-circuiting, which in turn constrains further growth of the expanding subsystem. This constraint is most binding in the relation between the expanding economic system and the adjusting noneconomic human systems because the human agents in the economic system are the same as those in the noneconomic human systems.

The attempt to create single purpose instruments to match specific targets is ultimately self-defeating in a closed system where everything must be connected in order to be stable and viable. Instruments must of necessity be multipurpose in such a system. And since instruments and targets cannot be separated meaningfully, all variables in the system must be determined together if they are to be compatible. Thus, how far the economic system can expand through functional specialization does not depend on the availability of energy and material resources but on how long it takes for the disruptions it imposes on the other subsystems to become significant sources of disruption to the economic system itself and on whether the values of the relevant variables in the economic system can be compatibly determined.

While the foregoing suggests that limits to growth exist, it does not set a timetable for when growth must ultimately cease. In this respect, there is little difference between this view of the growth process and that which views economic growth in terms of strictly limited resources. Yet this paper has taken one further step in that it describes what limits the process of technological bypassing of resource restrictions. To the extent that this limitation is better understood, those who formulate economic policy are better equipped to deal with it.

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