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The cybernetics of competition: a biologist's view of society

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THE CYBERNETICS OF COMPETITION: A BIOLOGIST'S VIEW OF SOCIETY[1]

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... What is offered here is one biologist's conception of the foundations of social and economic theory. "What presumption:" social scientists may say. Admitted; but biology, as Warren Weaver has put it, is "the science of organized complexity" – and what is the social scene if not one of organized complexity? Some of the principles worked out in one field should be at least part of the theoretical structure of the other. Particularly relevant are the principles of cybernetics, the science of communication and control within organized systems.

The cybernetic model can be carried over into economics, as shown in Figure 1, which depicts the control of price in the Ricardian economic scheme. The well-known course of events can be read from the figure. We see that negative feed-back produces stability about a "set point", which Ricardo called the "natural price". The model would be more realistic if it were constructed in terms of profit rather than price, but for historical continuity we retain the classic Ricardian element price. As with the biological example previously used, the meaning of "natural" can, in general, only be determined *ex post facto*. The word "natural" is here (as elsewhere) a verbal cloak for ignorance. Nevertheless, it or an equivalent word is needed to remind us of the state of affairs. There is mystery here. It was this mystery together with

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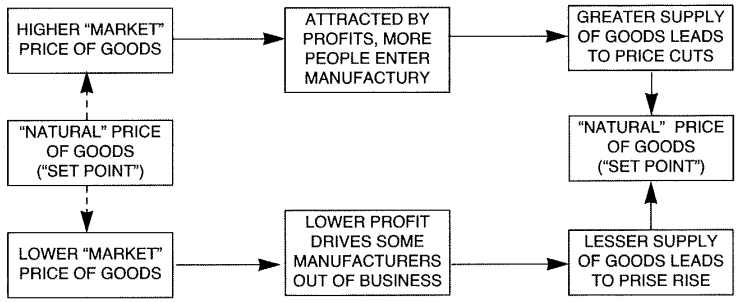

Figure 1. *Cybernetic regulation of price, in the Ricardian model.*

the unpremeditated consequences of the economic cybernetic system that led Adam Smith to speak of an "Invisible Hand".

An effective cybernetic system produces stability, *i.e.*, fluctuations within limits, and this we esteem. A system that produces a stable temperature, or a stable population, or a stable price, seems to us somehow right. When we examine any cybernetic system were discover that it is more or less wasteful. The thermostated room wastes heat; the natural population wastes lives; the economic system produces price wars and business bankruptcies. We may refine the controls and minimize the losses (of heat, or of money, for example), but a close examination of the system convinces us that there must always be some losses, waste in some sense. This is so because the controls that serve to produce equilibria are themselves so many modes of loss. Accounting procedures, insurance programs, police forces, sweat glands, electric fans, predation, crowd diseases, delicate thermostats – all these are forms of waste. We do not regret them, for the negative feedback produced by each of these elements acts as a check to some kind of uncontrolled and ruinous positive feedback. But each negative feedback device has its price, and we cannot get rid of one form of loss without incurring another. In a deep sense we see that some waste is inevitable and natural, and we recognize as immature the man who compulsively tries to do away with all waste. We recognize as pathological the goal of a waste-free world. This recognition is an important element in that complex of temperament that we label "conservative". Insofar as we think deeply, we all, of necessity, partake of this temperament to some extent.

But because the mature person acknowledges the inevitability of some waste, it does not follow that he must be reconciled to any amount and kind of waste. In the first excitement of discovering the beauties of economic

cybernetics, David Ricardo quite naturally made such an error. In speaking of the cybernetic system that stabilizes the population of laborers, Ricardo wrote: "When the market price of labour is below its natural price, the condition of the labourers is most wretched: then property deprives them of those comforts which custom renders absolute necessaries. It is only after their privations have reduced their number, or the demand for labour has increased, that the market price of labour will rise to its natural price..."

Attention should be called to the use of the word "natural" in this question. It would be antihistorical to expect Ricardo to speak of the "set point of labor" inasmuch as the term "set point" was not used for another century; but that is not the only criticism that can be made of the word "natural". Looking at the problem through the eyes of Stephen Potter, what do we see? Plainly, that an advocate is likely to use the word "natural" in order to insinuate approval of the "natural" thing into the mind of his auditor. By so doing, the advocate frees himself of the necessity of developing a defensible argument for the "natural" thing – for who can disprove of that which is "natural"?

This attack on the use of the word "natural" is more than a mere Potterian counterploy, as is clearly shown by the following defense given by Ricardo:

> Labour, like all other things which are purchased and sold, and which may be increased or diminished in quantity, has its natural and its market price. The natural price of labour is that price which is necessary to enable the labourers, one with another, to subsist and perpetuate their race, without either increase or diminution.
>
> These then are the laws by which wages are regulated, and by which the happiness of far the greatest art of every community is governed. Like all other contracts, wages should be left to the fair and free competition, of the market, and should never be controlled by the interference of the legislature.

This passage leaves no question in our mind that Ricardo identified the momentary state of things in his own time as "natural" and that all attempts to modify it further by new legislation were "unnatural" and hence improper in some deep sense. With rare exceptions, most of us post- Ricardians have been unwilling to accept this view. We will accept the starvation of field mice; but not that of human workers. Ricardo, at least on paper, accepted both. But – perhaps because of a delicate consideration of the feelings of others? – he used a most elegant euphemism for the facts. "It is only after their privations have reduced their number", he wrote; and insisted that "wages should be left to the fair and free competition of the market". The market must be free, that we may enjoy the blessings of cybernetic stability. Most of us now think that Ricardo's price is too high. We are willing to make use of "unnatural" controls of the price of labor even if it means losing some of our freedom. The history of the labor movement since Ricardo's time may be regarded as

one long struggle to substitute other forms of waste for the "natural" form which Ricardo, who was not a laborer, was willing to accept.

THE COMPETITIVE EXCLUSION PRINCIPLE

Perhaps more important than the humane argument just given against the Ricardian model is a theoretical argument which indicates that the cybernetic system he described is fundamentally unstable. Before we can discuss this matter we need to introduce a biological principle known by various names but recently called the "competitive exclusion principle". The historical origin of this principle is complex; no one man can be given credit for it. In the last decade it has become increasingly clear that it is basic axiom of biological theory; and it will be my argument here that it is basic also to sociological and economic theory. But first, let us develop the principle in an exclusively biological context.

Consider a situation in which two mobile species, X and Z, live in the same habitat and also live in the same "ecological niche", i.e., live exactly the same type of life. Species X multiplies according to this equation:

$$x = Ke^{f^t}, \tag{1}$$

where x is the number of individuals of species X at time t; e is the base of natural logarithms; K is a constant standing for the number of x at $t=0$; and f is a constant determined by the "reproductive potential" of the species.

Species Z multiplies according to this equation:

$$z = Le^{g^t}, \tag{2}$$

in which the constants have the same meaning as before (though, in the general case, with different values).

Suppose these two species are placed in the same universe to compete with each other. What will happen? Let us represent the ratio of the numbers of the two species, x/z, by a new variable, y. Then:

$$y = \frac{Ke^{f^t}}{Le^{g^t}}. \tag{3}$$

Since K and L are both constants, they can be replaced by another constant, say C; and making use of a well-known law of exponents, we can write:

$$y = Ce^{f^t - g^t} = Ce^{(f-g)^t}. \tag{4}$$

But f and g are also constants, and can be replaced by another constant, say b, which gives us:

$$y = Ce^{b^t}, \tag{5}$$

which is, of course, our old friend, the equation of exponential growth. The constant b will be positive if species X is competitively superior, negative if it is species Z that multiplies faster.

What does this mean in words? This: in a finite universe – and the organisms of our world know no other – were the total number of organisms of both kinds cannot exceed a certain number, a universe in which a fraction of one living organism is not possible, one species will necessarily replace the other species completely if the two species are "complete competitors", *i.e.* live the same kind of life.

Only if $b=0$, *i.e.*, of the multiplication rates of the two species are precisely equal, will the two species be able to coexists. Precise, mathematical equality is clearly so unlikely that we can ignore this possibility completely. Instead we assert that the coexistence of species cannot find its explanation in their competetive equality. This truth has profound practical implications.

HAVE WE PROVED TOO MUCH?

It is characteristic of incomplete theory that it "proves too much", *i.e.*, it leads to predictions which are contrary to fact. This is what we find on our first assessment of the competitive exclusion principle. If we begin with the assumption that every species competes with all other species, we are forced to the conclusion that one species – the best of them all – should extinguish all other species. But there are at least a million species in existence today. The variety seems to be fairly stable. How come?

There are many answers to this question. I will discuss here only some of the answers, choosing those that will prove suggestive when we later take up problems of the application of the exclusion principle to human affairs. The following factors may, in one situation or another, account for the coexistence of species.

Geographic isolation. – Before man came along and mixed things up, the herbivores of Australia (e.g., kangaroos) did not compete with European herbivores (rabbits). Now Australians, desirous of retaining some of the aboriginal fauna, are trying desperately to prevent the working out of the exclusion principle.

Ecological isolation. – English sparrows introduced into New England excluded the native bluebirds from the cities. But in very rural environments bluebirds have, apparently, some competitive advantage over the sparrows, and there they survive today.

Ecological succession. – It is not only true that environments select organisms; in addition, organisms make new selective environments. The conditions produced by a winning species may put an end to its own success. Grape juice favors yeast cells more than all others; but as the cells grow they produce alcohol which limits their growth and ultimately results in new predominant species, the vinegar bacteria. In the growth of forests, pine trees are often only an intermediate stage, a "subclimax", being succeeded by the climax plants, the hardwood trees, which out-compete the pines in growing up from seeds in the shade of the pine tree.

Lack of mobility. – The universal application of the exclusion principle to plants is still a controversial issue, which cannot be resolved here. It may be that the lack of mobility, combined with certain advantages to being first on the spot, modify the outcome significantly. Although this explanation is questionable, it is a fact of observation that a pure stand of one kind of plant hardly ever occurs.

Interbreeding. – If two competing populations are closely enough related genetically that they can interbreed, one group does not replace the other, they simply merge. This does not end competition; it merely changes its locus. The different genes of the formerly distinct groups now compete with each other, under the same rule of competitive exclusion.

Mutation. – Continuing with the example just given one gene never quite eliminates another because the process of mutation is constantly producing new genes. The gene for hemophilia, for example, is a very disadvantageous gene; but even if hemophiliacs never had children (which is almost true), there would always be some hemophiliacs in the population because about three eggs in every 100,000 produced by completely normal women will be mutants that develop into hemophiliac sons.

THE CYBERNETICS OF MONOPOLY

We are now ready to take a second look at the Ricardian thesis. The model implicit in his writings may not unfairly be stated as follows. We conceive of a single product manufactured by a number of *entrepreneurs*, each of whom must, for simplicity in theory construction be imagined to be engaged in

the manufacture of this product only. Under these conditions the Ricardian cybernetic scheme diagrammed in Figure 1 will prevail – but only for a while. History indicates that the number of *entrepreneurs* is subject to a long-term secular trend toward reduction. In the early days there were many scores of manufacturers of automobiles in the US; today there are less than a dozen. Ball-point pens, transistors – every new product – have followed the same evolution. The history of the oil industry (to name only one) indicates that under conditions of perfect *laissez faire*, competition has a natural tendency to steadily decrease the number of competitors until only one is left. In industries with heavy overheads this tendency is a consequence of the economy of size. But even without this size effect, a simple extension of the competitive exclusion principle into economics shows that a reduction in the number of competitors will take place as the more efficient *entrepreneurs* squeeze out the less efficient, until ultimately only one is left. If this were not so, we would have to conclude that the free enterprise system has no tendency to produce the lowest possible price; or, to put it differently, that it has no tendency to produce the maximum efficiency. Either conclusion would deny the claims to virtue put forward by the defenders of the free enterprise system.

If a monopoly is produced what then? Here is a question which Ricardo did not face. At first glance one might say that the monopoly price should be stable, because if it were to rise, new entrepreneurs would be attacted to the field and would lower the price. But this is a naïve view. We know that it is more difficult to start a business than to continue one, and consequently a monopolist can maintain a price considerably above the "natural price". Furthermore, a realistic model must include much more than we have indicated so far. We must consider the whole complex of phenomena that we include under the word "power". Social power is a process with positive feedback. By innumerable stratagems a monopolist will try to manipulate the machinery of society in such a way as to ward off all threats to re-establish negative feedback and a "natural" cybernetic equilibrium. And, as history shows, the monopolist in one field will seek to extend his power into others, without limit.

What has just been said about business monopolies applies equally to labor monopolies, *mutatis mutandis*. Insofar as they meet with no opposition, there is little doubt that labor monopolies seek to produce an ever higher price for labor. At the same time, they protest the appearance of business monopolies. Contrariwise, unopposed business-men seek to promote a free market in labor while restricting it in their own field (by "Fair Trade" laws, for instance). It is not cynicism but simply honesty that forces us to acknowledge that Louis

Veuillot (1813-1883) was right when he said: "When I am the weaker, I ask you for liberty because that is your principle; but when I am the stronger I take liberty away from you because that is my principle". In other words, such verbal devices as "principles", "liberty", and "fairness" can be used as competitive weapons. Each purely competitive agent, were he completely honest and frank, would say, "I demand a free market – but only for others". It is, in fact, a natural part of my competitive spirit to seek to remove from my field the natural competition on which the validity of the Ricardian scheme rests.

Such an analysis, which is based on the observed behavior of competing groups, may seem depressing. Rather than dwell on the possible emotional consequences of the facts, let us see what we can do about arranging the world to our satisfaction. Let us try to enlarge the model of our theory. To do this we acknowledge that we are not only unconscious "purely competitive agents", but that we are also capable of being conscious. We can predict the results of our own actions, as well as the results of the actions of those opposed to us. We acknowledge that words are actions, actions designed to influence others. Because we can see that others resort to high-flown rhetoric when they want to influence us we become suspicious of our own arguments. We operate under the basic and parsimonious rule of the Theory of Games, which says that we must impute to others intelligence equal to our own. Under these conditions we seek the boundary conditions within which the rule of *laissez faire* can produce stability.

THE LIMITS OF *LAISSEZ FAIRE*

Laisez faire has a strong emotional appeal; it seems somehow right. Yet we have seen that, in the limit, the rule fails because of the positive feedback of power. Can we rationalize the rule of *laissez faire* by harmonizing it with boundary conditions?

I suggest that there is, in biology, a useful model already at hand. Consider the cybernetic system that controls the temperature of the human body. This system works admirably. So well does it work that, for the most part, we can safely adopt a *laissez faire* attitude toward our body temperature.

The system works without conscious control or planning. But only within limits. If the environmental stress is too great, temperature control fails. At the upper limit, too great a heat input raises the body temperature to the point where the physiological thermostat no longer functions. Then higher

temperature produces greater metabolism, which produces more heat, which produces higher temperature, which – and there it is, positive feedback, leading to death, to destruction of the whole system. Similarly with abnormally low temperatures. The working of the system is shown in Figure 2. There is a middle region in which a *laissez faire* attitude toward control of the environment works perfectly; we call this middle region the homeostatic plateau. (The word "homeostatic" was coined by W. B. Cannon to indicate *constancy-maintained- by-negative-feedback*). Beyond the homeostatic plateau, at either extreme, lies positive feeback and destruction. Plainly, our object in life must be to keep ourselves on the homeostatic plateau. And insofar as it is within our power to affect the design of a system, we would wish to extend the plateau as far as possible.

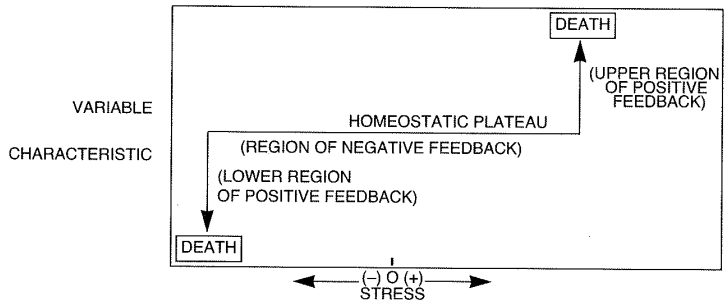

Figure 2. The cybernetics involved in the survival of a system.

Is this not the model for all cybernetic systems, sociological and economic as well as biological, the model on which ethics must be based? The desire to maintain absolute constancy in any system must be recognized as deeply pathological. Engineering theory indicates that excessive restraints can produce instability. In psychiatry also, the desire for complete certainly is recognized as a most destructive compulsion. And in the history of nations, attempts to control rigidly all economic variables have uniformly led to chaos. The psychologically healthy human recognizes that fluctuations are unavoidable, that waste is normal, and that one should institute only such explicit controls as are required to keen each system on its homeostatic plateau. We must devise and use such controls as are needed to keep the social system on the homeostatic plateau. On this plateau – but not beyond it – freedom produces stability.

We can do this only if we explicitly give up certain superficially plausible objectives which are incompatible with stability. In the realm of economics,

the most dangerous will-o'-the-wisp is the word "efficiency". Consider the classical Ricardian economic system. If we decide that all waste is bad and that we must maximize efficiency, then we will stand admiringly by and watch the competitive exclusion principle work its way to its conclusion, leaving only one surviving *entrepreneur*, the most efficient. And then? Then we find that we have a tiger by the tail, that we have allowed the positive feedback of power to go so far that we may be unable to regain anything that deserves the name of freedom. It is suicidal to seek complete efficiency. The Greek Solon, said, "Nothing in excess", to which we must add, not even efficiency. Whatever it is that we want to maximize, it cannot be efficiency. We can remain free only of we accept some waste.

How are we to keep a social system on its homeostatic plateau? By laws? Not in any simple way, for the effect of an action depends on the state of the system at the time it is applied – a fact which is, I believe, not systematically recognized in the theory of law. An act which is harmless when the system is well within its homeostatic boundaries may be quite destructive when the system is already stressed near one of its limits. To promote the good of stability, a law must take cognizance not only of the act but also of the state of the system at the time the act is performed. In his effort to obtain the maximum individual freedom, it is to be expected, of course, that "economic man" will try to defend his actions in terms of some tradition-hallowed "absolute" principles that take no cognizance of the state of the system. Absolutists of all sorts may, in fact, be defined as men who reject systematic thinking.

Consider this question: Should a man be allowed to make money, and keep it? In the history of Western capitalism our first approximation to an answer was an unqualified Yes. But as we became aware that money is one means of acheving the positive feedback of power, we looked around for curbs. One of these is the graduated income tax, which most men would now defend as a reasonable brake to the positive feedback of economic power. Yet it can easily be attacked as being "unfair", and in fact has been so attacked many times. As late as 1954 (according to a press report) the industrialist Fred Maytag II, speaking to a meeting of the National Association of Manufacturers on the subject of discriminatory taxes, issued this clarion call for action: "The hour is late, but not too late. There is no excuse for our hesitating any longer. With all the strength of equity and logic on our side, and with the urgent need for taking the tax shackles off economic progress, initiative is ours if we have the courage to take it".

One cannot but have a certain sympathy for the speaker. He is right when he says that the existing tax structure is contrary to "equity". But if discussion

is to be carried on in terms of such abstractions, Mr. Maytag would find his opponents introducing the word "justice" and saying that this is more precious than equity. Rather than use such verbal bludgeons, we should think operationally in terms of the homeostatic plateau. We should think in terms of systems rather than individual acts. That this sort of thinking presents difficulties for the law is admitted; but it is clear also that we have made some progress in the solution of these difficulties, e.g., in the graduated income tax. It is clear also that our systematic thinking has not produced perfect solutions to our problems (e.g., it is still possible to become a millionaire *via* the capital gains route).

Indeed, the recognition of the relevance of the whole system in judging the desirability of an individual act can be traced back to antiquity. One of the greatest of the technical social inventions of ancient Athens was that of *ostracism*, which was invented by Cleisthenes. We are told:

> One a year the popular Assembly deliberated on whether any citizen should be required to go into exile for ten years on the grounds that his presence in Athens was a threat to the constitution. If the Assembly voted to hold an ostracism, a second vote was taken. Then, if six thousand citizens wrote the same name on an *ostrakon*, or potsherd, the man named must leave Athens for then years. But he did not lose his citizen-ship, his goods were not confiscated, he did not even suffer disgrace. In fact, it was only the man of great ability who was likely to be ostracized, yet the possibility of ostracism was a constant deterrent to overweening political ambition.

In other words, ostracism was a device aimed at stopping the positive feedback of power, a tool designed to maintain the political system on a homeostatic plateau. Recognition of the dangers of this positive feedback must surely be almost universal among practical men and produces the most diverse stratagems, many of which would seem quite paradoxical to one who was ignorant of the positive feedback of power (as adolescents in our society often are). For instance, we are told that "in the early history of the Church, bishops had to take two solemn oaths at the time of their ordination. The first oath was that they would discharge the duties of that office faithfully in the sight of God and man. The second oath was called the oath of '*Nolo episcopari*' – 'I don't want to be a bishop'..." Those who frequent the university campuses of our own time will surely have noted that one of the best ways to achieve a deanship is to insist that one doen't want to be dean (but too loudly!). Competition and the desire to limit power produce strange strategies.

THE PERSISTENCE OF VARIETY

An important part of the unfinished work of theoretical biology revolves around the question of variety: how are we to account for the variety of

the living world? The competitive exclusion principle points always towards simplification; yet the world remains amazingly, delightfully complex.

The same problem exists in economics. Why do there continue to be so many competing units? The economist's problem is, I suspect, even further from solution than the biologist's, but we can briefly list some of the social factors, which resemble those mentioned earlier in the biological discussion.

Geographic isolation. – A less efficient company may be able to coexist with a more efficient one if it is a considerable distance and if transportation charges are heavy, as they are for instance, in the coal and steel industry. (It is interesting to note that major steelmakers of the United States two generations ago tried to negate this factor by enforcing the "Pittsburgh-plus" system of pricing).

Product differentiation. – In biology, ecological differentiation is the necessary condition for coexistence; in economics, product differentiation plays the same role. Patents, copyrights, and mere advertising gimmicks enable entrepreneurs partially to escape pure competition.

Mergers prevent extinction in economics in the same sense that interbreeding prevents extinction in biology.

In the social realm we have in addition various peculiarly human characteristics that contribute to the persistence of variety. Curiosity, envy, dislike of boredom, yearning for destruction are a few of the factors which work against the efficiency of the market and hence to perpetuate variety. We are a long way from understanding the economic system. It is, however, transparently clear that any satisfactory over-all theory of economics must include a large measure of psychology in it. The Homo economicus of classical theory has been useful as a first approximation only.

THE IDEA OF A SYSTEM

One of the most important ideas in modern science is the idea of a system; and it is almost impossible to define. There are a number of good essays available on this subject. Here we will try to define by example.

Our first example is a caricature from the nineteenth century – the idea of a system that connects the welfare of England with the existence of old maids. The argument is simple: old maids keep cats, cats eat rats, rats destroy bumbledee nests, bumblebees fertilize red clover, and red clover is needed for horses, which are the backbone of English character training. *Ergo* the strength of England depends on a bountiful supply of old maids. Now that

is a caricature, but it gets across the idea that the many cybernetic systems of nature are connected in complex ways. So complex are they that we can seldom predict exactly what will happen when we introduce a new element into a system. By way of illustration consider the following examples from three different fields of biology.

Ecology. – Charles Elton tells the following history.

> Some keen gardener, intent upon making Hawaii even more beautiful than before, introduced a plant called *Lantana camara*, which in its native home of Mexico causes no trouble to anybody. Meanwhile, some one else had also improved the amenities of the place by introducing turtle-doves from China, which, unlike any of the native birds, fed eagerly upon the berries of *Lantana*. The combined effects of the vegetative powers of the plant and the spreading of seeds by the turtle-doves were to make the *Lantana* multiply exceedingly and become a serious pest on the grazing country. Indian mynah birds were also introduced, and they too fed upon *Lantana* berries. After a few years the birds of both species had increased enormously in numbers. But there is another side to the story. Formerly the grasslands and young sugar-cane plantations had been ravaged yearly by vast numbers of army-worm caterpillars, but the mynahs also fed upon these caterpillars and succeeded to a large extent in keeping them in check, so that the outbreaks became less severe. About this time certain insects were introduced in order to try and check the spread of *Lantana* and several of them (in particular a species of Agromyzid fly) did actually destroy so much seed that the *Lantana* began to decrease. As a result of this, the munahs also began to decrease in numbers to such an extent that there began to occur again severe outbreaks of army-worm caterpillars. It was then found that when the *Lantana* had been removed in many places, other introduced shrubs came in, some of which are even more difficult to eradicate than the original *Lantana*.

From this example (ans scores of comparable ones are known) it is easy to see why it is so difficult to secure the permission of the US Department of Agriculture to import any species of plant or animal. However, though we are very conservative about the introduction of biotic elements into our ecological systems, we show the most juvenile irrespondibility in our attitude toward new chemicals. To get rid of insects, we spray promiscuously with such potent poisons as Malathion. As a result, we kill not only millions of insects, but also thousands of birds. Because birds are a great natural negative feedback for insect populations, using insecticides often causes a secondary increase in the numbers of insects later. We may refer to this as a "flareback" – thus verbally acknowledging our failure to think in terms of systems. We are only now beginning to see the magnitude of the problems we have created for ourselves by unsystematic thinking, for which belated insight we are significantly indebted to Rachel Carson's book Silent Spring.

Embryology. – Beginning about 1960 a drug known as "thalidomide" became an increasingly popular sedative in Europe. It seemed superior to all others in effectiveness and harmlessness. But by the end of 1961 a most painful disillusionment had set in. When taken during the early weeks of pregnancy, it frequently interfered with the development of the limb buds of

the child, resulting in the birth of a child suffering *phocomelia* – seal-limbs, little flipper-like hands, without long arm bones. In addition, there were other variable defects of the ears, digestive tract, heart, and large blood vessels; strawberry marks were common. Only a minority of the children whose mothers took thalidomide during the first trimester developed *phocomelia*, but so widespread was the use of the drug that the number of cases produced in West Germany alone in two years' time probably exceeded 6,000. This experience contributed to a re-evaluation of the whole idea of therapy, particularly of newly pregnant women. The developing embryo is a set of cybernetic systems of the greatest complexity. Coupled with the high rate of change during the early weeks is a high sensitivity to foreign chemicals inserted into the system. To a growing extent, physicians are loath to permit a newly pregnant woman to take any drug if it can possibly be avoided.

When we think in terms of systems, we see that a fundamental misconception is embedded in the popular term "side- effects" (as has been pointed out to me by James W. Wiggins). This phrase means roughly "effects which I hadn't foreseen or don't want to think about". As concerns the basic mechanism, side-effects no more deserve the adjective "side" than does the "principal" effect. It is hard to think in terms of systems, and we eagerly warp our language to protect ourselves from the necessity of doing so.

Genetics. – When a new gene is discovered, it must be named; this is accomplished by naming it for some conspicuous effect it has on the organism. But when a very careful study is made, it is found that a mutant gene had not one effect but many. For example, close analysis of one mutant gene in the laboratory rat has shown no less than twenty-two well-defined effects, including effects on ribs, larynx, trachea, vertebrae, lungs, red blood cells, heart, teeth, and capillaries. Yet all these effects spring from a single chemical change in the genetic material of the fertilized egg. In the early days, genetistics often used the word "pleiotropy" to refer to the multiple effects of genes. Now it seems scarcely worthwhile to use this word because we are pretty sure that all genes are pleiotropic. The word "pleiotropy" is a fossil remnant of the days when geneticists failed to have sufficient appreciation of the developing organism as a system.

Pleiotropy presents animal and plant breeders with one of their most basic and persistent problems. The breeding performance of the St. Bernard dog will serve to illustrate the problem. Crosses between St. Bernard and other breeds of dogs produce a large proportion of stillborn or lethally malformed puppies. The trouble apparently lies in the pituitary gland, which is over-active. When we look closely at the adult St. Bernard, we see that its abnormally large head

and paws correspond to "acromegaly" in humans, a condition also caused by an overactive pituitary. The St. Bernard breed is, in fact, standardized around this abnormality. Why are not the causalitive genes more deleterious to the breed? Undoubtedly because there are other, "*modifier*", genes which alter the whole genetic system so that it can tolerate the effects of the "*principal*" genes. The production of a new breed built around some distinctive gene often takes a long time because the breeder must find, and breed for, a multitude of modifier genes which create a genetic system favorable to the principal gene. This work is almost entirely trial and error; along the way the breeder must put up with large losses in the way of unseccessful systems of genes.

THE FEASIBILITY OF HUMAN WISHES

The dream of the philosopher's stone is old and well known and has its counterpart in the ideas of skeleton keys and panaceas; Each of these images is of a single thing which solves all problems within a certain class. The dream of such cure-alls is largely a thing of the past. We now look askance at anyone who sets out to find the philosopher's stone.

The mythology of our time is built more around the reciprocal dream – the dream of a highly specific agent which will do only one thing. It was this myth which guided Paul Ehrlich in his search for disease-specific therapeutic agents. "Antitoxins and antibacterial substances are, so to speak, charmed bullets which strike only those objects for whose destruction they have been produced", said Ehrlich in voicing this myth. Belief in the myth has inspired much fruitful research; but it is a myth, as the phenomena of allergies, anaphylaxis, auto-immunization, and other "side-effects"show us. It is our myth, and so it is hard to see.

One of the inspired touches in Rachel Carson's *Silent Spring* is her use of "The Monkey's Paw", a story which W. W. Jacobs built around our modern myth. In this story a man is allowed three wishes. He wishes first for money. He gets it. It is brought to his door as compensation for his son's death in the mill. Horrified, the father wishes his son alive again. He gets that wish too – his son comes to the door looking as he would after such an accident. In desperation, the father wishes everything back as it was before he was given the three wishes.

The moral of the myth can be put in various ways. One: wishing won't make it so. Two: every change has its price. Three (and this one I like the

best): we can never do merely one thing. Wishing to kill insects, we may put an end to the singing of birds. Wishing to "get there" faster, we isult our lungs with smog. Wishing to know what is happening everywhere in the world at once, we create an information overload against which the mind rebels, responding by a new and dangerous apathy.

Systems analysis points out in the clearest way the virtual irrelevance of good intentions in determining the consequences of altering a system. For a particularly clear-cut example, consider the Pasteurian revolution – the application of bacteriology and sanitation to the control of disease. We embarked on this revolution because we wished to diminish loss of life by disease. We got our wish, but it looks now as though the price will be an ultimate increase in the amount of starvation in the world. We could have predicted this, had we taken thought, for Malthus came before Pasteur, and Malthus clearly described the cybernetic system that controls populations. The negative feedbacks Malthus saw were misery and vice – by which he meant disease, starvation, war, and (apparently) contraception. Whatever diminution in effect one of these feedbacks undergoes must be made up for an increase in the others. War, it happens, is almost always a feeble demographic control; and contraception is not yet as powerful as we would like it to be: so, unless we exert ourselves extraordinarily in the next decade, starvation will have to take over. Like the father in "The Monkey's Paw", we wanted only one thing – freedom from disease. But in the system of the world, we can never change merely one thing.

Suppose that at the time Pasteur offered us his gift of bacteriology – and I use the name "Pasteur" in a symbolic way to stand for a multitude of workers – suppose at that time that some astute systems analyst had drawn a Malthusian cybernetic diagram on the blackboard and had pointed out to us the consequences of accepting this gift. Would we have refused it? I cannot believe we would. If we were typically human, we would probably have simply called forth our considerable talent for denial and gone ahead, hoping for the best (which perhaps is what we actually did).

But suppose we had been what we like to dream we are – completely rational and honest, and not given to denial? Would we then have rejected the gift of disease control? Possibly; but I think not. Is it not more likely that we would, instead, have looked around for another gift to combine with this one to produce a new, stable system? That other gift is well known of course: it is the one Margaret Sanger gave us, to speak symbolically again. It is a gift we are now in the process of accepting.

In terms of systems, we can give this analysis:

System	*Stability*
Malthusian	Yes
Pasteurian	No
Sangerian	Possibly
Pasteurian-Sangerian	Yes

A systems analyst need not, when confronted with a new invention, reject it out of hand simply because "we can never do merely one thing". Rather, if he has the least spark of creativity in him, he says "We can never do merely one thing, therefore we must do several in order that we may bring into being a new stable system". Obviously, in planning a new system he would have to examine many candidate- ideas and re-examine our value system to determine what it is we really want to maximize. Not easy work, to say the least.

IS PLANNING POSSIBLE?

Some of the most excruciating questions of our time hinge on feasibility of planning. Is good planning possible? Is it possible to devise a planned system that is at least as good as a free system? Can the free market be dispensed with without losing its desirable virtues?

There is no dearth of literature supporting and condemning planning. Rather than add to this double battery of polemic literature. I would like to take a different approach. I would prefer to adopt an agnostic attitude toward the principal question and ask a second question: If successful planning is possible, what are its preconditions? If we can see these clearly, we should be in a better position to answer the principal question. The major points at issue seem to me to be the following.

1) Can it be shown, before instituting a plan, that all significant factors have been taken account of? It is not easy to see what the nature of the proof would be; and in any case, the consequences of past planning attempts do not make us optimistic.

2) Are we sure that we can predict all possible interactions of factors, even when we have complete knowledge of them? This is not as disturbing a question now as it was in the past. Any system of equations that can be solved "in principle" can be turned over to computing machines, which are immensely faster, more patient, and more reliable than human beings; and

all computing machines operate under the Magna Charta given them by A. M. Turing.

3) Granted that we can predict a new and better stable system, can we also devise an acceptable transition? The many social systems known to historians and anthropologists represent so many points in space and time. The transitions from one to another are usually obscure; or, when recorded, are known to involve great human suffering and immense wastage of human resources. In general, transitions seem more feasible for small populations than large – but will small populations ever again exist?

4) Can we take adequate account of the reflexive effect of knowledge and planning on the actions of the planned and the planners? I have argued elsewhere that a satisfactory theory of the social sciences must be based on recognition of three classes of truth. No one, to my knowledge, had tackled this fundamental problem.

5) Can it be shown that programming, in the light of the reflexive effect of knowledge, does not lead to some sort of infinitive regress? Only so can solutions be achieved.

6) Can the calculations be carried out fast enough? Modern calculating machines, with their basic operations measured in microseconds, are marvelously speedy. But the number of operations required may be astronomical, and the 3.1557×10^7 seconds available in each year may not be enough.

7) Can we persuade men to accept change? A casual survey of important reforms effected in the recent past shows that each of them took about seventy-five to one hundred years for completion. It is a general impression (and a correct one, I think) that the speed at which social problems appear is now accelerating. But is there any indication that the rate of solution is also accelerating? We seem to need some basic reform in people's reaction to proposed changes. Would this demand a new sort of faith? And in what? Science? Truth? Humanism?

8) Will any plan we adopt have adequate self-correcting mechanisms built into it? It is one of the virtues of a market economy that any error in judgment as to what people want is soon corrected for. Price fluctuations communicate needs to the managers. But in a planned economy, it had been often noted, planners who make errors are likely deliberately to interfere with the free flow of information in order to save their skins. Can a planned system include uncloggable channels of information?

Such seem to me to be the principal difficulties in the way of planning. Whether they will ultimately prove insuperable, who can say? But for the

foreseeable future, I suggest there is much to be said for this analysis by Kenneth Boulding:

> ... I believe the market, when it works well, is a true instrument of redemption, though a humble one, not only for individuals but for society. It gives the individual a sense of being wanted and gives him an opportunity of serving without servility. It gives society the opportunity of coordinating immensly diverse activities without coercion. The "hidden hand" of Adam Smith is not a fiction.
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> There are forces operating in society, as there are within the human organism, which make for health. The doctor is merely the cooperator with these great forces in the body. The doctor of society – who is equally necessary – must also be a humble cooperator with the great forces of ecological interaction, which often restore a society to health in spite of his medications. It is precisely this 'anarchy' which Professor Niebuhr deplores which saves us, in both the human and the social organism. If we really established conscious control over the heartbeat and the white blood cells, how long would we last? Health is achieved by the cooperation of consciousness with a largely unconscious physiological process. Selfconsciousness is not always an aid to health, either in the individual or in society.

The problem of planning will not soon be disposed of, or soon solved, but perhaps some false issues can be avoided if we make a distinction between "planning" and "designing". By planning I mean here what I think most people have in mind, the making of rather detailed rather rigid plans. The word designing I would like to reserve for the much looser, less detailed, specification of a cybernetic system which includes negative feedbacks, self-correcting controls. The classical market economy is such a design. Kenneth Boulding when he speaks of "the market, when it workds well" is, I believe implicitly referring to the biologist's model of homeostasis shown in Figure 1. The classical market should not be called natural, for it is a truly human invention, however unconsciously made. It is not universal. It has been modified continually as men have groped toward better solutions. I would submit that the proper role for conscious action is the ethical evaluation of many possible homeostatic systems, the selection of the best possible one, and the refinement of its design so as to make the homeostatic plateau as broad as it can be, thus maximizing both social stability and human freedom.