Adaptive Economics and Economic Development

Richard H. Day and Yiu-Kwan Fan*

I. The Developing Economy, the Adapting Agent

Economic development is a process of accumulation, decumulation and structured change. It involves accumulation of capital and population, a decumulation of exhaustible resources and a shift from established modes of production and consumption to newer forms of economic and social activity. It often improves the fortunes of some, perhaps allowing in less developed countries an escape from a low income trap. It frequently involves a decline in fortune for others as old ways of life lose in the competition of resources and the distribution of product.

From time to time inventions and innovation inject new opportunities for economic expansion, suddenly placing advantage in the hands of early adaptors who pave the way for the transformation of society. And from time to time the last vestiges of some ancient culture, the last survivors of a declining people, disappear forever, leaving nothing but scattered artifacts hastily cast aside by the burgeoning classes that fill their space.

Theories of development, especially the growth theories of the past quarter century, have often been conceived in terms of aggregative indexes such as gross product, capital stock and total population. They incorporate a course structure of more or less fixed social and technical relations that suppress the role of the individual. But development involves an interaction between individuals and their environments. In the attempt to control their environments, individuals plan and initiate changes, implement them, and by so doing place themselves in the turbulent current of socio-political-economic forces as the previous situation is perturbed in ways that were not anticipated. As the process runs its course, people adapt to the changing environment by reacting to it as much as by controlling it; and when they reach a new state of adaptedness, it is generally time for

*University of Southern California and University of Hong Kong
another round of plans, actions, perturbations, changes and adaptations. As economic agents play a central role in the process, understanding their behavioral patterns is crucial for understanding development, which depends not only on aggregate productivity, population growth, and the general level of savings, but also on the way economic plans are formulated and how actions are executed in response to environmental conditions.

It would seem appropriate to name the archetypical decision maker in [developmental] disequilibrium "adaptive man." Adaptive man is an agent who makes short-horizon plans, not because he is irrational, but because he is (and knows he is) seldom prescient; he is cautious in adapting to a changing environment because tradition and experience suggest that caution is often a wise tactic in the game of economic survival; he responds to feedback from the market and the behavior of other agents because the task of estimating competitors' behaviors far exceeds the capacity of any individual's computational ability, even as it far exceeds the capacity of the largest and most sophisticated economic modeling center. Day and Singh [1977 p. 15].

The farmer in LDC's facing the prospects of agricultural modernization is an excellent example of the adaptive man.

The uncertain dependence upon weather and the inability to prevent crop disease and pests leave the farmer at the mercy of an unpredictable environment over which he has little control. Where subsistence farms dominate, there is very little margin for error, because the outcome of production decisions determines survival. The farmer's willingness to innovate may be tempered by the fact that he cannot afford to be wrong; the opportunity cost of an unfavorable outcome is very high, even when such outcomes rarely occur. The farmer is, therefore, likely to depart from the tried and traditional with a lag. After all, his information about outcomes is derived from long experience (his own and his forebears) and is based upon an intimate knowledge of environment. As he is confident in the survival value of traditional activities, the marginal payoff between them and new ones must be large for him to change. He must have confidence based on experience—his own or a successful neighbor's—to justify modifying traditional modes of behavior.

The basic ingredient of adaptive behavior according to these observations must be caution, not probability. Caution alone is sufficient to explain why small changes in relative prices or in the quantities of traditional inputs are unlikely to
bring about any long-run departure from traditional equilibrium, as argued by Schultz some time ago.

Closely related to caution, and partly explaining its existence is the fact that all economic decisions that have possible future outcomes are based upon more or less vague anticipations. Anticipations must be based upon the knowledge of the past behavior of events and upon guesses about the environment. In traditional agriculture the rate of change is slow, so that past information is a reliable guide to the future. This reliability breaks down when large structural changes begin to occur, as is typically the case in transformation. As a result, it is very difficult for farmers to predict when the only objective information available to them is based on past traditional events. The greater the rate of change, the less dependable will be the future, and the greater the reliance on some mechanism to feed back information about the relationship between action and events in the environment. A feedback mechanism based on actual outcomes makes it possible (with luck) to adjust anticipation in the right direction. Thus feedback becomes an essential element in the analysis of the decision behavior of traditional farmers.

A special case of feedback is the diffusion process that conditions the adoption of technology. As is well known, the farm manager in advanced countries is not always willing to adapt immediately to new alternatives for production or investment. His responses is distributed over time in a manner well described by exponential or S-shaped learning curves. In less developed countries similar behavioral patterns have emerged. The breakdown of age-old practices takes time partly because the supply of inputs must go through a development process of its own. This process places external constraints on the adoption of technology. In addition, adoption is internally constrained by a learning process that proceeds as more and more farmers gain familiarity with and confidence in their ability to exploit successfully the new opportunities. Therefore, activities that are feasible from the technological and financial points of view are further circumscribed by adaptive constraints that accommodate the cumulative effects of experience and observation of neighbor's experiences (Day and Singh [1977 pp. 16-17]).

What is true about farmers in LDC's is also true of farmers in economically advanced countries. It is also true of industrial managers and entrepreneurs, bankers and government bureaucrats, all of whom must formulate plans and cautiously adapt to changing circumstances without the benefit to complete information and with the aid of
only limited memory and computational powers.

If "adaptive man" is a better representation of decision makers in a changing environment than "rational man", then the path of economic development should be viewed as a sequence of states, each member of which has evolved from its predecessor according to the adaptive behavior of the economic agents involved. In each period the agents react to a changing environment, taking into account their own perceived constraints and current objectives based on available information flowing through the economic and natural environment from previous periods. Their decisions jointly determine the next state of the economy through a structure only accounted for in part in the individual plans. Because the plans are imperfectly coordinated, and are based on anticipations that are seldom fulfilled, they rarely lead to equilibrium actions in which supply equals demand and technical and social efficiency prevail. Instead, the economy as a whole searches its way through a complex terrain, stretch by stretch, and as it moves along it undergoes an irreversible metamorphosis.

II. Toward an Adaptive Theory of Economic Development

If we understand that economic development is basically a disequilibrium process, then it is not surprising to note that it has rarely been a smooth course with balanced growth and harmony. Indeed it is usually an imbalanced counterpoint of growth and decline: growth in production and capital, decline in traditional economic activities and sources of livelihood. It involves changing values, adjustment out of equilibrium, improving fortunes for some and declining fortunes for others. It involves overlapping waves of activity, sequences of growth, decay, and demise that occur beneath the surface of aggregate growth as new technology is introduced, competes with already established technology, rises to dominance, only to be replaced more or less gradually by still newer modes of production or consumption.

In theorizing about economic development, we believe that three important features of reality should be emphasized. These are, first, important or strategic details of technology that condition possibilities for change; second, imperfect or suboptimizing decision-making rules that approximate actual practice; and third, disequilibrium mechanisms in which some types of economic activity flourish while others decline.

In order that these elements can be incorporated in a formal model, it is necessary as the first objective,

to develop an operational, mathematical representation of development that incorporates essential features of the process as it
unfolds. This formal representation must be capable of incorporating strategic details of technology, decision making, and environment relevant for the time and place under investigation. Also it must, insofar as possible, draw on and be consistent with direct observation of the process itself. It must be operational—not in Samuelson's sense of being capable of refutation in an ideal experiment—but in the sense that it can be approximated by a specific mathematical structure, quantified with plausible data, simulated on the computer.

Having accomplished this objective, the model builder must, as a next objective, validate his representation of the development process. Because his model is realistic in its constituent components, the model builder, in pursuing this objective, is looking for evidence that his model is mistaken in its representation of reality. Such evidence can then be used, not as a basis for rejecting the entire edifice, but as a guide to changing the model so that its approximation of reality is improved.

Once satisfied that the model works and that it approximates reality with useful accuracy, the model builder is ready to consider applications. Applications involve understanding past history, making conditional projections, comparative dynamic analyses, and comparative static analyses (Day and Singh [1977 pp. 186-187]).

Such an approach falls within the realm of a diversely developing but more or less coherent methodology called adaptive economics, the central ingredients of which we shall now summarize.¹

Adaptation as an Agent-Environment Interaction

Beginning with the observation that economic events exhibit change and development, adaptive economics takes as its first axiom that economic experience is determined by a system of cause and effect in which the change in the system at any time is governed by its state at that time. It proceeds by decomposing the system into two parts; one representing the behavior of a part of the process of special interest which we may call—quite arbitrarily—the agent, and the other representing all other parts of reality which we call—equally arbitrarily—the environment, or more generally as the interaction of agent and environment. The "agent" may be a person, a household, a firm, a group of firms, or even an entire economy, depending on the pur-

¹ The summary which follows is based on Day [1975], [1976] and on an unpublished nontechnical survey prepared for the Electric Power Research Institute by the first author.
pose at hand. The "agent" therefore must be understood here to be a purely formal entity.

The output of the agent is called an act. It is based on the current output of the environment and the agent's past act. The mechanism that connects inputs and outputs may be called an adaptor. Likewise the environment generates an output which we may call an environmental state. This is derived from an input consisting of the previous state and the agent's act by means of a mechanism which we may call a transitor or environmental operator. We arrive in this way at the concept of an adapting system consisting of an interacting adaptor and transitor (agent and environment).

Systems of Adaptors

The environment of a given economic agent includes other agents. The agent himself may be thought of—in so far as his actual mode of behavior is concerned—as a collection of coordinated adaptive functions. In either case we have a system of adaptors. There are three distinct but closely related types of such systems. These are (1) the adapting economy, (2) the adapting organization, and (3) the adapting algorithm.

The adapting economy is a collection of agents who adapt to each other and to the "outside" environment. It includes cases in which the number of agents is so large that direct adaptation to other agents, even through feedback, would require so many linkages that effective action would be unthinkable. In such systems adaptation to other agents occurs, in part, indirectly through the environment. For example, the "market", by means of prices, communicates information about the entire system to each agent without his having to monitor any but his own economic activity. In this way markets economize interagent linkages. Of course, direct (lagged) linkages in the form of "conjectural variations" are also included in the notion of an adapting economy and have been studied in well-known theories of oligopoly that go back to Cournot.

The adaptive organization is a collection of agents who adaptively coordinate their activity, pursue some common purpose and share some benefits. A hierarchy or multi-level structure may exist among these linkages in which agents play differentiated roles, in this way coordinating activity to take advantage of specialization. The adapting economy includes, of course, the notion of a collection of adapting agents and organizations.

When the internal structure of adaptation is the focal point of interest, concern is with the adapting algorithm, a collection of adaptors which is coordinated for the purpose of solving specific problems. The notion of an adapting algorithm is quite general, for
individual agents, organization and economies solve problems: they consume, produce and coordinate supply and demand. For some purposes, its explicit use may embroil the economist in too much detail. He may prefer to treat the agent or organization as a kind of black box and focus on the "external" interactions.

From a purely formal point of view all three of these systems are composed of two basic structures, parallel and hierarchical, that may be combined to give many different structures of interaction. Thus, we can conceive of parallel adaptors representing either independent firms or adaptive functions, each member or function of which may be further decomposed into a hierarchical subsystem of managerial units or computation steps.

Meta-adaptation

Adaptation as defined so far involves the interaction of agent and environment according to fixed rules of behavior for a fixed agent or population of agents. If we are to consider how a given process comes into being or if we are to inquire how a system changes (or may be changed) from one structure to another then we come to a more complex type of adaptation which may be called meta-adaptation in which rules of behavior or the population of agents, or both are variables.

Three forms of meta-adaptation may thus be distinguished. In evolution the population of agents is a variable that is determined at any given time by the previously existing population interacting with its environment through forces of competition, cooperation and selection. This concept was of course developed to explain the progress of biological populations, but its application to socio-economic organizations is of obvious relevance.

Humans, at least, possess the ability to create in the course of their behavior new rules of adaptation, which may or may not be passed on to future generations. This selection or modification of adaptors for a given agent or population of agents through conscious effort may be called cultural adaptation, a type of meta-adaptation so important that society as a whole and many of its institutions set aside resources for use by specialists in this function such as, engineers, management scientists, and economists. Individuals, too, set aside resources, time and money for learning new modes of behavior through education and training. Cultural adaptation enables agents to survive in the face of evolutionary forces that would spell their demise if they did not acquire new modes of behavior. It also enables them to improve their performance in the sense of some criterion or outcome measure.

When both evolution and cultural adaptations are present we
have cultural evolution which allows for the response of agents to their environment, the modification of strategies or modes of behavior by given agents and the modification of the population of agents itself.

Adaptive Functions

The elemental decomposition of an adaptive agent is into two constituent parts; that of sensor which filters and processes information about the environment, and that of effector which responds in terms of behavior to the informational cues. Very simple combinations of these two elements can have great survival power as is effectively illustrated by Lotka’s example of the mechanical mouse (Lotka [1924]). To model behavior completely, however, a decomposition of these two constituents must be recognized. The sensor function may be divided into observation, memory (or information storage), and information processing which results in planning data (Marschak [1968]). The effector function may be divided into planning and implementing activities. The latter distinction recognizes that plans are not always realized and that an individual or organization must react to an unfolding situation according to a procedure quite different from those characteristic of rational decision-making or planning. Individuals embody the distinction in separate reflecting and effecting capacities. Many organizations institutionalize it in separate staff and command systems.

Space does not permit a survey of all the mechanisms that have been or might be used for representing the working of these several functions. Instead, three canonical categories will be summarized: (i) the system of switches and rules, (ii) learning algorithms, and (iii) economizing or explicit optimizing.

Rules and Switches

A function is a set of ordered pairs; the first member is the input (argument) and the second the output (image) of the adaptor. When the function is represented by a closed form expression or formula it is an operator or rule that associates an image to each possible argument. Rules may be derived from economizing theory, by a statistical analysis of inputs and outputs when the agent is regarded as a “black box”, or they may be identified by direct observation in the case of persons and organizations. In the latter case one speaks of behavioral rules.

Not all functions used in mathematics can be computed. When they can be computed they are called computable or recursive (Arbib [1969]). A procedure for computing an image for a given argument is an algorithm. A recursive function, rule, or operator then must represent the “equilibrium” of some algorithm. It is for this reason
that virtually all models of economic behavior must possess implicit conditions for temporary equilibrium—a technique used to simplify the full dynamic structure of economic behavior. If one is to make explicit the full structure of adaptation, one must appeal to the class of simplest functions or rules from which algorithms for all other rules may be constructed. Adaptive behavior is founded on the existence of such rules.

Among the simplest rules is the switch, which has the function of changing action from one mode to another depending on the environmental state and which modifies the paths or loops through which the system flow occurs. Numerical algorithms for computing functions consist of systems of switches and simple arithmetical rules. Computer simulation models of directly observable behavior in economic organizations employ analogous systems. Examples of the latter are the behavioral economic models of Cyert and March [1963], the system dynamics models of Orcutt et al. [1963], and the general systems simulation models of Manetsch et al. [1971].

Homeostasis

All living systems, including man in his economic activity, possess critical variables that must be maintained within the boundaries of certain critical sets if they are to survive. In general these critical sets depend on the current situation as determined by an admissibility operator. The agent must possess an adaptor that leads to an action within the admissible region determined by this operator. The agent survives so long as the admissible set is non-empty and his action belongs to this set. In this case we shall say that the agent exhibits homeostasis in the general sense (Ashby [1967]; Day [1975]). If either of these conditions fails then the agent goes out of existence and the system collapses to a transistor that maps a given environmental state into a succeeding environmental state.

A mechanism for achieving homeostasis is the negative feedback control device or servomechanism that adjusts actions on the basis of an observed discrepancy between a desired or target value of the critical variables and their experienced values. Extensively developed by Cannon [1939] in the context in human physiology, the idea was first applied to economic behavior by Simon [1952], March and Simon [1958], Cooper [1951], Boulding [1962], and Forrester [1966] and is the basis of the flexible accelerator (Goodwin [1948], Chenery [1952]). Systems that behave according to such rules we shall say exhibit homeostasis in the specific sense. It may be noted that homeostasis in the specific sense is in essence an algorithm for minimizing the distance between target and observed critical outcomes and implies a preference for outcomes closer to the target than others. This distance can clearly be thought of as a “disutility”.
We thus see in this widely observed form of adaptation an implicit optimizing scheme.

**Behavioral Learning**

Economizing behavior as described, for example, by the marginalist Marshall involved incremental, economically improving adjustments. Optimality of full equilibrium only occurred—if at all—through a converging sequence of marginal changes in behavior. Marshall's focus, however, like many of his contemporaries, was on the characteristics of the state of equilibrium, assuming it was brought about. But if one is to understand the adaptive mechanism that underlies economizing then one must study the process of marginal adjustment itself and ask, under what conditions will it bring about optimality and at what speed? And, as explicit optimizing takes time, involves the consumption of other resources, and is far from easy, the process of optimizing itself is a part of the economizing problem. When investigating such issues, learning algorithms must be constructed that describe economizing as an adapting process.

The canonical form for learning algorithms is a system of switches and rules in which the rules governing behavior at any time is determined when the performance measure belongs to the rule's associated switching set. A change in the performance measure sufficient to bring its value to a different set of values causes a change in action or a switch in the rule governing behavior. Simple examples can readily be constructed using four elemental principles of learning: (1) successful behavior is repeated; (2) unsuccessful behavior is avoided; (3) unsuccessful behavior is followed by a search for alternative modes of behavior; and (4) behavior becomes more cautious in response to failure. Well founded in psychological theory and experimentation, models incorporating (1)–(3) have been the basis of the behavioral theory of the firm developed by Cyert and March [1963]. In Day [1967] and Day and Tinney (1968) it is shown that behavioral learning models, augmented by failure response (4), can converge to the economist's traditional economic equilibria for individual agents or two agent teams with stationary environments. Recently, empirical evidence has been assembled that indicates that businesses are actually governed by such learning rules.

The essence of the behavioral learning model is an extremely simple local or approximate optimizing of marginal variations in action based on an extremely limited knowledge of past results. This characteristic is shared by mathematical algorithms for computing optima of complex unconstrained or constrained optimization problems. Optima for such problems cannot usually be intuited but must be approximated through a process of trial and error based on local, approximate suboptimization with feedback. Gradient methods are
transparent examples of such algorithms in which search is directed along a locally steepest path of ascent (or descent) with increasing caution represented by shortening step lengths as marginal payoffs decrease or local optima are overshot. The locally steepest path is the gradient (or constrained gradient) which solves a local maximization problem.

**Optimizing With Feedback or Recursive Programming**

The analogy between elemental learning behavior and optimizing algorithms exposes a fundamental duality between optimizing and learning. The solutions of complex optimizing problems must be learned by what are in effect elemental adaptive processes, and elemental adaptive processes that exhibit learning involve optimization in a simple way. This duality motivates a consideration of the class of all processes which represent behavior or planning computations by sequences of recursively connected, local, approximate, or behaviorally conditioned suboptimizations with feedback or recursive programming models. Such models appear in a great variety of special forms that share a common mathematical structure.

From a purely formal point of view they are three component systems involving data, optimizing and feedback operators. The *data operator*, which subsumes observation, storage, and processing functions, defines how the "parameters" or data entering objective and constraint functions depend on the current state of the system as a whole. The *optimizing operator* describes the dependence of certain decision or choice variables on objective and constraint functions that in turn depend on the various parameters or data. The *feedback operator*, which subsumes implementation and environmental transition functions, specifies how the succeeding state of the system depends on the current optimal decision variables, the data, and the current state. Given an *initial state* for the system the data for an optimization can be generated in which parameters or data upon which any one optimization are based depend on past optimizations and parameters or data in the sequence.

It is essential to note that while each solution in the sequence of recursively generated optimizations satisfies certain optimality properties, the sequence as a whole need not and in general will not. Indeed some models of this structure can be constructed that will generate pessimal performance, just as other examples can be shown to generate optimal performance. We emphasize that the behavioral learning model and gradient algorithms are simple examples of this general approach.

In recursive programming models of economic behavior constrained maximizing is used to describe the plans or intended behavior of an economizing agent or group of agents, but with the
added assumption that actual performance is determined by additional forces unaccounted for in the individual optimizations. These additional forces may act on the agent through environmental and behavioral feedback in the form of physical and financial accumulations (and decumulations), through information incorporated in estimates of current states and forecasts of anticipated states, and through behavioral rules that make allowances for future decision making, that modify objectives on the basis of past behavior and that limit change from established behavior as a tactic for avoiding uncertainty.

The description of a decision-maker who proceeds according to a succession of behaviorally conditioned, suboptimizing, more or less myopic decisions corresponds reasonably well to behavior observed in many business firms and government agencies. Nonetheless, strategic considerations can also be incorporated into a recursive programming model by using optimal control or dynamic programming for the optimizing operator in which the payoff (or expected payoff) of an anticipated sequence of future actions is maximized subject to a simplified feedback operator that represents the perceived environmental feedback operator. A plan consisting of optimal intended future behavior is derived, or, more generally an optimal strategy is derived which specifies how current behavior should be controlled given current information. When such a “strategic” optimizing (dynamic programming) operator is imbedded in a “true” or “complete” feedback structure, the model as a whole now becomes a recursive programming model that represents an agent or several agents who are forward looking and whose plans have strategic quality, but whose actual behavior is conditioned by forces whose exact structure is not incorporated in the optimizing calculations. In such a model the “true” optimal strategy is not used unless the true transitor is assumed to be perceived by the agents.

As we have already observed, the paradigm of a behaviorally conditioned, suboptimizing economic decision-maker is also a good description of certain algorithms for computing solutions to complicated planning models. These algorithms are developed by decomposing the original problem into a simpler problem or set of simpler problems and a feedback rule that describes how the simple problems should be modified on the basis of past solutions, so that when they are solved by a known, convenient, economical method the solution will be closer than before to the optimum of the original complicated problem. One may think of the original complicated problem as an “environment”, the simplified optimization problem as a decision maker’s suboptimizing tactic, and the feedback rule as a means of using past decisions and feedback from the “environment” to obtain a new approximate decision problem. The sequence of suboptima
should converge to the desired overall optimum, but in general, one can only approximate the desired solution in this way. The degree of approximation depends on the planner's computing budget and how efficient the algorithm is. The parallel with the gradient and behavioral learning algorithms to which we referred in the preceding section should be evident. For a review of recursive programming models and their predecessors see Day and Cigno [1978].

**Adaptive Programming or Dual Control**

When applying strategic considerations to the problem of adaptation the agent must, if he is to achieve global optimality, account for all the decision functions, observation, storage, processing, planning and implementation, and in choosing a course of action must consider the advantage to be gained by allocating present resources to learning about the system through conscious experimentation as compared to their allocation for maximizing current performance given the current level of knowledge of the system's operation. Formal models which embody these considerations are called adaptive control or adaptive programming models and seem to have been originated by Fel'dbaum [1965] in a generalization of Bellman's dynamic programming and or stochastic programming techniques (Aoki [1967]). Extensively studied by control engineers alternative models of this general type have been described in several recent surveys and need not be elaborated here (Aoki [1977]).

Imagine now a process in which aspects of the "true" environmental feedback structure are newly learned with the passage of time. Then the adaptive control model to be optimized depends recursively on the "true" external environment. A model of this complete system is a recursive programming model involving suboptimization with feedback as before, but in which intended behavior at each stage is influenced by an attempt to learn as well as to control optimally.

The more inclusive is the range of decision-making considerations explicitly incorporated within the adaptive control framework, the more complex, costly, and time-consuming the implied algorithm for obtaining "optimal" decisions. Such costs indeed rise more or less exponentially with the level of detail accommodated so that the model must become an extreme simplification of actual operating decisions.

The implication is that an adaptive programming strategy is simply one way of planning in a state of partial knowledge. In practice it must involve substituting a complex and extremely costly computational algorithm for "real time" behavioral learning, servomechanistic procedures, or simple tactical optimizing. But if the
decision-maker has something to learn about the structure of the environment (and not just its parameters), then one cannot be sure that sophisticated strategies will, in fact, perform better than the simpler ones they replace. Whether or not and under what conditions they will perform better depends on the “true” environment planning model and how stable the structure is when plans roll and knowledge evolves in interaction with the “true” environment. These questions, indeed, pose a host of theoretical problems of deep significance and wide relevance.

Evidently a universal form of explicit optimizing does not govern evolution. Instead the form of optimizing is itself a product of learning i.e., of adaptation, and as activity adds to the store of knowledge, the conception of what exists, what is possible, what is desirable, and how to make plans evolves. In adaptive economics, then, adaptive control models form merely one among several fundamental classes of techniques for describing the adaptive procedures by which humans and organizations solve their economic problems.

Cultural Adaptation and Evolutionary Adaptation

In cultural adaptation, in which rules of behavior (adaptors) are modified, one has a process more or less analogous to elemental adaptation except that change is occurring in a function (adaptor) space as well as in the agent's action space. The subsystem governing the selection (or modification) of adaptors or behavioral rules is based on an orchestration of activities in which the memory, data processing, and observation functions are called investigation; the planning function which involves synthesizing new rules is called theorizing or model building; and the implementation function involves practice, education, training, or indoctrination.

People’s manners of responding to unfolding events change as they mature. The seeking of immediate pleasure, the direct avoidance of pain and the dominance of curiosity become less apparent. Reflective activity emerges and rational choice gradually plays and increasing role in some domains of activity. Analogously, as organizations mature rules of thumb make way for scientific management. In either case, however, rational modes of operation are limited in scope and contend with habit, tradition, impulse and imitation. Emerging behavior probably follows a weighting of rational and nonrational rules in which the emphasis on one or the other evolves on the basis of experimentation and the knowledge of past results and in which the superiority and eventual dominance of rational behavior cannot be assumed or taken for granted.

Agents must exhibit homeostasis in the general sense (defined above) if they are to survive. Evolutionary adaptation—as contrasted
with the cultural adaptation just considered—occurs when actions carry critical variables outside their critical sets of values. Of course, humans are subject to ordinary biological selection mechanisms (and these are thought by some extreme advocates of evolutionary theory to exert a powerful influence on human development even within the historical epoch (Darlington [1969])). Economic organizations add wholly new and characteristically (if not uniquely) human modes of competition and selection that transcend the callous profligacy of the biological world. Bankruptcy, for example, allows for the demise of firms and households while preserving the human participants. It is this kind of organizational evolution that is the special province of economics and whose formal study has been launched impressively by Winter [1964], [1971].

Disequilibrium Mechanisms

All those considerations of adaptation and evolution must lead to an emphasis on disequilibrium phenomena in adapting—as opposed to adapted—systems: the disappointment of expectations, imperfect coordination of separately managed enterprises, the inequation of supply and demand, inefficiencies in the allocation of resources, and declining as well as improving fortunes of some participants in the system. The extent of these phenomena may be greater at one time than at another. At all times they pose threats to survival. They virtually always bring about demise of individual firms—the number of bankruptcies in the United States running in the thousands per month, even in good times! They occasionally conspire to drive industries, regions, even entire nations to ruin. The primary concern of the firm then must be for its survival while the institutional development of society must be guided to a considerable degree by the need to maintain viability in the face of disequilibrium.

For the individual as well as for the organization, caution is an element strongly influencing adaptive behavior and a part of cautious behavior is the maintenance of stocks of unused resources and the existences of organization slack to absorb unpredictable divergences between plans and realization. In addition organizations evolve whose functions are to mediate disequilibrium transactions and to sustain critical variables within homeostatic bounds. Stores, for example, function as inventories on display mediating the flow of supplied and demanded commodities without the intervention of centralized coordination or of complicated and time-consuming market tatonnement procedures. Banks and other financial intermediaries regulate the flow of purchasing power among uncoordinated savers and investors, and mediate the flow of credits and debts that facilitate intertemporal exchanges without simultaneous bartering of goods. Ordering mechanisms with accompanying backlogs and variable delivery
delays together with inventory fluctuations provide a flow of information that facilitate adjustment to disequilibria in commodity supplies and demands.

To these mechanisms must be added insurance and other transfer schemes such as unemployment compensation that place resources in the hands of agents who would possess no admissible action without them.

Models of adapting economies will contain elements representing these and other devices for maintaining economic viability. The preservation of such institutions is always threatened when a system is working relatively well, for they create unused stocks and apparent inefficiencies. Frequently, they are instituted after a disaster when they were needed and later abandoned if they go unused for long, only to be reinstated after the next crisis, in this way ineffectually reacting to experience. It is, of course, their existence when not needed that makes possible their effective contribution when disequilibrium conditions are running strong. In any case their emergence is a central feature of the adapting economy.

III. Some Adaptive Development Models

As outlined above adaptive economics is a coherent family of concepts and a realistic, yet rigorous mode of economic thinking. It is not a single, unified model of an economic system. Indeed, quite varied models incorporate elements of the approach, numerous disciplines have evolved related ideas, and many of the central concepts can be traced back through the literature to the classic period. It would be impossible within the confines of this paper to survey even the most important and seminal contributions. Instead, we shall briefly summarize the class of models involving economizing with feedback.

The first explicit, formal example of this class is due to Cournot [1838] in the context of duopoly theory. It was used by Walras [1874] in tatonnement theory, implicitly by Marshall [1890] in his quasi-rent theory of investment, implicitly by Kaldor [199] and Leontief [1934] in the cobweb theory of markets, and by Chamberlin [1931] in his theory of monopolistic competition and again, this time explicitly, by Leontief [1958] in a model of economic growth. The germ of a general approach is seen in Hicks [1939], Hart [1942], and more explicitly in Modigliani and Cohen [1963].

The tool that lends itself readily to the formal modelling and analysis of these theories is recursive programming, which as we have seen is a sequence of optimization problems in which parameters or coefficients of any problem in the sequence are functionally dependent on the optimal variables of preceding members of the sequence. The class of recursive linear programs was discussed in Day [1963] and
a general theory sketched in Day [1971], [1975] and in Day and Kennedy [1970]. They have been used extensively to explain agricultural and industrial development. Day [1963] constructed a model of agricultural development that described production and investment in any one period as the outcome of a linear programming problem which incorporated "flexibility constraints" that constrained choices to lie within bounds that were functionally dependent on the preceding year's choices. The model was extended and applied to regional studies of agricultural development by Schaller and Dean [1965], Heidtbaes [1969], Cigno [1971], Singh [1971], Mudahar [1972], and Day and Singh [1977]. The latter three studies focus on the green revolution in the Indian Punjab.

The Day-Singh study uses a multi-goal recursive linear programming model and was used to generate a detailed, quantitative chronicle of input utilization, capital-labor substitution, technological change, growing productivity, and structural change in the demand for labor and other factors. Activity analysis is used to represent production, financial, consumption, and marketing activities, and the choice among available activities (as given by available technology and within the limits that learning allows) is guided by multiple goals arranged in absolute priority order. These goals are: (1) farm subsistence, (2) cash consumption-savings, (3) safety and (4) profit maximizing. The first three are satiable with finite activity levels. Thus in each period, short-run profits are maximized given that subsistence is allowed for, that the cash consumption goal can be met, and that the amount of working capital allows safe-enough changes in production and investment activities.

Another recent application of the adaptive approach to agricultural development is found in Ahn and Singh [1978], in which the regional development of Southern Brazil is projected into the 1980's under alternative policy assumptions about price supports for wheat production and credit plans for agricultural mechanization. The transformation of the Rio Grande do Sul region from predominantly range livestock production to intensive crop production is studied, with emphasis on its impacts on resource allocation, changes in credit demand, and income distribution. Three farm-group models are knitted into a recursive programming model with technical constraints, behavioral constraints, and feedback relations. Alternative policies of price supports and credit subsidies are then tested on the model, generating varying projections for the next decade.

Industrial development models have also been constructed using recursive programming tools. These include the steel industry (Tsao [1966], Abe [1973], Nelson [1973]), the coal industry (Tabb [1967]), and the petroleum industry (Lindsay [1974]). These microeconomic studies of key industries help to provide explanations for the dyna-
nics of industrial growth and decline.

Planning is viewed as passing through four stages. First, data concerning input-output structures, production and inventory goals, input supplies, behavioral rules, production costs, and annual investment charges are formulated. Second, feasible production goals are determined. Third, production-investment activity levels are planned that minimize production and investment costs, where the latter are determined by a cash-flow, payback criterion. Fourth, given estimated expanded capacity, “actual” production is performed at minimum variable cost leading to a final estimate of production activity levels.

The heart of the approach is the third stage in which investment levels are determined. In this stage, investment is assumed to be motivated by two distinct considerations: (i) capacity expansion to meet anticipated sales and (ii) replacement of existing plant and equipment by technologically superior alternative capital goods to lower production costs. Because of this second consideration excess capacity can be generated even in the face of stable or declining demand for as long as an investment will “pay for itself” by reducing production costs to return the sacrificed capital in a sufficient period of time (the payback period), investment will occur.

The rate of investment in these models is constrained, first by adjustment bounds that reflect hedging against uncertainties, second by adoption constraints that reflect learning, and third by abandonment constraints that reflect inertia in departing from established practice. Because of these constraints and because of the behavioral feedback relations, investment may continue in obsolescent capacity until the willing expansion in new technology increases enough. Likewise, abandonment of obsolescent or obsolete technology may be limited by the reluctance to “plunge” in the latest techniques, as well as by an inherent inertia in the planning process.

The model generates capital capacity trajectories with overlapping wavelike appearances. If a good is profitable, it follows the adoption constraint for a time, until the adjustment rule becomes tight. Eventually, as capacity expands in superior techniques, old techniques will change at less than their maximum potential rates, perhaps increasing for a time, then declining and finally, declining at a maximal rate determined by depreciation or disinvestment activities.

In a variant of this general approach prices are treated as endogenous variables by introducing market demand functions. Behavior is assumed to be based on profit maximizing using price forecasting rules and cautious suboptimizing as before. In these studies exemplified by Day and Tinney [1969] and Day, Morley, and Smith [1974], the strongly stabilizing effect of the precautionary constraints
is brought out. Still, phase switching is evident and in various cases bankruptcy is generated leading to either a sector-wide breakdown, or to the exit of firms or groups of firms in an explicitly evolutionary development (Muller and Day [1978] and Mudahar and Day [1978]).

The studies just summarized each involves individual agricultural or industrial sectors. At least two models using the RP approach have so far been developed that represent multisectoral development interactions, one based on Hicksian temporary equilibrium theory and the second involving intersectoral disequilibrium. We will consider these briefly in turn.

Using the recursive programming approach, Cigno [1978a] has devised a model of capital accumulation which takes into account myopic suboptimization and the effects of learning on shaping the course of the economic system. In his model, it is shown that if the accounting prices obtained from the dual solution are used to evaluate the stocks available to the decision-maker (firm, planning board, economy) at the beginning of a period t (say, the current period), the total value of these stocks will be equal to the present value of the profit stream accruing to the decision-maker over T periods (the planning horizon). Making use of this fact, a multi-period decision problem can be reduced to a single-period one, hence allowing changing expectations, preferences, technologies and other revisions without scrapping a laboriously constructed multi-period plan every time. Under certain conditions, temporary and dynamic general equilibria exist, and a von Neumann path is shown to be a special case of dynamic equilibrium. The model has been applied to study the dynamic behavior of the market system with exhaustible natural resources (Cigno [1978b]), and the process of capital accumulation and technological change in the Italian Province of Padova (Cigno [1971], [1978c]).

An adaptive, multi-sector model of economic development is the framework used by Fan [1974, 1978] and Fan and Day [1978] to study the interrelationship between the development process in agriculture and industry and rural-urban migration in LDC’s. In contrast to the Fei-Ranis and Jorgenson models which treat migration as a costless and instantaneous equilibrating process of intersectoral labor transfer governed by wages differentials, the Fan-Day study portrays migration as a disequilibrium process of environmental changes and adaptation. It focuses on the dynamics of the process itself, in particular on (1) what initiates the transfer; (2) how the transfer occurs; (3) how the process is sustained; (4) what are the limits to the transfer process; and (5) what is the relationship between labor transfer and labor absorption. The disequilibrium approach also distinguishes the model from the Harris-Todaro model [1970] which, though offering an explanation for urban unemploy-
ment, treats rural-urban migration as equilibrating marginal adjustments.

The Fan-Day model has three sub-systems (economic development, quality of life, migration), two areas (rural, urban), and six sectors (agricultural, rural nonagricultural, manufacturing, urban traditional, financial intermediaries, and the public sector). Production, investment, employment and financial activity levels for a given period within the agriculture and manufacturing sectors are represented by linear programming models, one for each sector. Activities within the other sectors are represented by behavioral equations involving adjustment to prevailing conditions. Feedback relations involving capital accumulation, income flows, labor supplies and working capital connect the sectors. The linear programming models include adaptive, flexibility constraints to represent cautious behavior. The model as a whole is a complex type of recursive linear programming system.

The financial intermediaries provide services to smooth out the economic activities of the sectors. The employment slacks in the rural and urban areas are taken up by the non-agricultural and urban traditional sectors respectively. Whereas the prices of the agricultural and manufacturing products are set exogenously in the world markets, the prices of non-agricultural produce and urban traditional services are determined in the domestic commodity market by market clearing and demand functions. Sectoral income and wages are jointly determined by institutional elements and the prices and volumes of sectoral outputs.

Qualities of life in the two areas are described by indices representing education, health facilities, housing conditions, pollution, crime, “bright lights” and alienation. These indices are influenced by the population densities and by government expenditures. Relative sectoral income levels and relative differences in rural and urban quality of life jointly generate the migration streams from one area to another. Such migration streams affect the distribution of population, hence the distribution of labor force, between the rural and urban areas. These effects diffuse throughout the entire system through the sector linkages and feedback relations, helping to shape the new state of the economy in the subsequent period.

The model is simulated for a stylized, small, over-populated, predominantly agricultural economy at the verge of industrialization and modernization. Emerging from the seventy-five-year simulated history of the economy are not only agricultural modernization and industrial development, but also phenomenal switches of economic activities, a long period of rapid urbanization accompanied by little industrial growth, a heavy stream of rural-urban migration with a
sizable counterstream of urban-rural migration, increasingly unbalanced spatial distribution of population, ever-worsening distribution of income as economic development proceeds before it gets better, unemployment and underemployment in both rural and urban areas, and other familiar phenomena of developing economies.

Other applications of recursive programming or of alternative adaptive models to economic development can be cited. But the brief review in this section should be adequate to point to the flexibility and richness of this approach for tracking the dynamics of developing economies.

IV. Summary and Conclusions

Neoclassical theories of economic development begin with axioms of rationality and rest on a presumption of market efficiency and equilibrium. Adaptive economics, on the other hand, begins with an assumption that change evolves from current conditions, and focuses on the economizing of partially informed agents whose transactions are imperfectly coordinated, who use various adaptive procedures such as servomechanisms, behavioral learning rules, suboptimization with feedback and the like, whose numbers, activities, rules of behavior and organization evolve. It is primarily the study of how economies adapt in disequilibrium and secondarily whether or not and if so how equilibria or states of adaptedness are achieved.

Static economic thinking often leads the econoimst to view the economic system as changing slowly and sluggishly toward optimum conditions and to recommend policies to accelerate adjustment. Adaptive models incorporating behavioral rules, such as cautious optimizing, information lags, and adjustment delays, describe explicitly the inertia governing the economic system. They explain how changes in any one short time interval are limited. Nonetheless, study after study, such as the ones summarized above, show that with the passage of time quite drastic changes are brought about, even though short-run movement are modest.

Explicit attention to dynamic processes consequently leads to a different perspective than obtained in static analysis. Instead of comparing the economy at one point in time to an equilibrium state, one focusses on the accumulation of short-run, inertia-bounded changes out of equilibrium. The impression one gets from this point of view is one of great and often rapid change after only a few years. Certainly, a generation, and often a decade, is adequate for producing pronounced alterations in commodity patterns and production technology.

Now change produces many "externalities". People are required to accommodate themselves to changing occupations, changing loca-
tions, and often to changing life styles. Such adaptation is achieved more readily by some than others. Moreover, various new imbalances are created even when old uneconomic activities are dying out. This phenomenon is seen in wide and varied agricultural settings. Uneconomic commodities and traditional techniques give way to new farm organization, technologies, and cropping patterns. Very often growth in industrial sector is not adequate to absorb the released rural workers. The consequence is severe short-run unemployment problems. It may well be that much less attention should be paid by policy-makers to accelerating adjustment and much more attention paid to controlling its speed and diminishing its costs.

In spite of their explicit incorporation of cautious change and inertia adaptive models have the capacity to display drastically changing “modes”, “stages”, or “phases” of behavior. For example, the rapid S-shaped growth of a commodity gives way to more or less uniform oscillations. The automatic switching from one technology to another and from one type of resource scarcity to another is typical of many industries.

The picture of economic activity which adaptive models give is of a sequence of more or less distinct periods of development characterized by distinct sets of resource scarcities and productive activities, and distinct qualitative characteristics of change (growth, cycles, stationarity, etc.). Such distinct periods do not come in some fixed or immutable order as proposed in the stage-making theories of economic history. Rather they come in a great variety of orders and in a great variety of types that depend on the initial technological, geographical and behavioral conditions of the economy in question.

To sum up, adaptive economics treats economic development as a process following from decisions taken by various economic actors who process partial information, adapt to external conditions using suboptimal strategies and behavioral rules and whose transactions occur in disequilibrium. The implied trajectories are not necessarily, or even usually, optimal. They often reflect situations in which unforeseen crises emerge out of formerly advantageous changes, and patterns in which some segments of a population—or some whole countries—become worse off while others become better off.

Adaptive economics attempts first to explain how development problems and crises emerge from the dynamic structure of the developing system. Then it attempts to identify policies that can be implemented while the economy is in disequilibrium and that will improve adaptation on the part of the system as a whole. It may be hoped that sufficient study of development from this point of view may help identify policies which can anticipate potential crises and moderate or eliminate them by preventative action.
References


