Adaptive Economics and Natural Resources Policy

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The purpose of these remarks is to consider a variously developing, yet coherent approach to economics differing sharply from, but closely related and complementary to optimality and general equilibrium theory, and which, I believe, has a special relevance for natural resources policy. The discussion is introduced by a reflection on the neo-laissez-faireism put forth by some of our most able colleagues as a result of their application of orthodox economics to contemporary resource problems. This is followed by a brief summary of some features of the contrasting theoretical approach I am here to advocate, and which I have referred to elsewhere as adaptive economics (Day 1975). Succeeding remarks point out a few properties possessed by models of this genre, properties that suggest a new perspective on economic policy in general and on natural resources policy in particular. This perspective is the subject of the concluding section.

On Laissez-Faire

At a recent conference on resource scarcity and economic growth,[1] Joe Stiglitz asserted that there is little evidence to suggest the existence of a resource problem, and even if there were, we should probably do nothing about it.[2] This statement would probably astonish laymen, perhaps even be thought bizarre by certain liberal politicians. To well trained economists, however, it is neither surprising nor malevolent. Through the study of optimization and equilibrium, economists gain an understanding of the efficiency of perfect competition. Through a knowledge of economic history, we derive a keen respect for the accomplishments of decentralized enterprise and market processes in overcoming scarcities as they emerge. Through experience with policy formulation and implementation, we acquire a healthy skepticism of the ability of government to improve economic performance as it evolves.

Thus, it is natural for economists to regard contemporary resource shortages as transitory phenomena that will be (or should be) eliminated by price-directed substitutions and by induced technological change. Besides, such empirical evidence of resource scarcity as exists is hotly contested, as was brought out, among other places, at the aforementioned conference on scarcity and economic growth.

Why, then, are we, members of the same intellectual fraternity, gathered here to discuss contemporary issues in resource economics? May I suggest that we are here because we do not believe our own orthodoxy? In my opinion, few economists pursue the subject for its own sake; rather, they pursue it in the belief that contemporary economic problems need solution through proper analysis and effective policy. This behavior reveals a further belief either (*a*) in the imperfection of the existing system: its social or technical inefficiency, its imbalances of supply and demand, its monetary instabilities, its persistent misallocation of resources eventually to bankrupt enterprises, its working to make individuals, groups, even entire cultures, worse off; or (*b*) that other competitive equilibria than those that are supposed to exist are better and should be brought about by a redistribution of resources through nonmarket policies.

Thus, while it may be natural for us to hold a prejudice in favor of market mechanisms, it is also common for us to find room in them for improvement, modification, or augmentation by alternative allocation procedures.

Having motivated a concern for policy I want now to look at a particular approach to

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[1] The conference on "The Economics of Natural Resource Scarcity," held at Resources for the Future, Washington, D.C., 17–18 Oct. 1976.

[2] Paraphrased from memory.

economic theory which, it is to be argued, lends a new perspective to policy.

On Adaptive Economics

The basic problem of adaptive economic theory is to explain how the dynamics of economic evolution are derived from the behavior of individuals and organizations. There are certain factors to be explained by this theory on the basis of plausible axioms of behavior.

The facts to be explained include, first, the emergence of complex trajectories of economic change involving growth, fluctuation, and decay, overlapping waves of specific production and consumption technologies and switches in the underlying structure of activity and resource constraints; second, the seemingly irresistible movements that harm some individuals, groups, and entire cultures, leading in extreme but not infrequent cases to their demise; and third, instabilities and inefficiencies that appear to be robust with respect to policies designed to control them.

The axioms of behavior, on the basis of which these facts are to be explained, formalize the following observations: (*a*) economic activity changes the environment within which further activity is conceived and executed: economic artifacts are more or less durable, including irreversible effects on the environment, such as pollution or resource exhaustion that follow as consequences of production and consumption activity; (*b*) economizing is carried out by agents who are partially informed, have limited memory and computational powers, and who can make only imperfect forecasts of the effects of their choices; (*c*) the current state of knowledge derives from, and can derive from only, the past operation of the system; (*d*) economic activity, including planning, takes time, so that delays intervene between plans, actions, and consequences; (*e*) plans and behavior are imperfectly coordinated, so economic behavior takes place out of equilibrium. Adaptive economics does not begin with structures of rationality and equilibrium (although those concepts are necessarily involved). Rather it 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 servomechanism, behavioral learning rules, optimization with feedback, and the like—and whose numbers, activities, rules of behavior, and organizations 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.

Note that our subject is not opposed to equilibrium theory. Quite the contrary, for concepts of rationality and equilibrium define states of optimal adaptation which provide a benchmark against which disequilibrium performance may be compared. But the convergence of adapting processes to optimal states is not to be taken for granted. In the biological world (of which we are of course a part), evolution proceeds by various trials and errors, producing local and temporary adaptation at best, more or less improving fitness sometimes, and monstrosities, anachronisms, and extinctions much of the time. In economics we encounter similar phenomena. Our interest in adaptation must, therefore, surely not be motivated by a desire to mimic in human affairs the blind profligate and callous mechanism that governs other species, as was advocated by the Social Darwinists, but rather to understand better and to make possible the more effective participation of human intellect in the evolutionary process that governs life, in general, and conditions human affairs, in particular.

It should also be noted that the concepts of economizing, economic equilibrium, adaptation, and evolution have been intertwined throughout much of their development. The biologist Darwin attributed his inspiration to the economist Malthus, while Marshall—most notably among neoclassical scholars—drew extensively on biological analogies in describing the process by which firms adapt to their market environment by means of incremental adjustments and by which low-cost firms drive high-cost competitors out of existence.

Although some economists, such as the great Ragnar Frisch, recognized the explicitly adaptive, evolutionary character of Marshall's economics, the latter have received much less attention than have the associated concepts of equilibrium or adaptedness for which Marshall is indeed primarily remembered.

But adaptive economics is not merely new skin for old wine. It is a body of theory in the process of construction and from which we should expect many new insights as its parts grow and mature.

Adapting in Disequilibrium

From a purely formal point of view it would appear that adaptive behavior takes two distinct forms, one of which is servomechanistic and which I shall call determined homeostasis and the second of which involves bounded rationality and which I shall call optimizing with feedback.

In the first form, determined homeostasis, actions are adjusted on the basis of an observed discrepancy between a desired or target value of one or more critical variables and their experienced values. Extensively developed by Canon, in the context of physiology, and by Brown and Campbell (for example), in engineering, the idea seems first to have been applied to the study of human behavior by Cooper, Simon, March and Simon, Boulding, and Forrester, and is the basis of the Goodwin-Chenery flexible accelerator (Goodwin, Chenery). It may be noted that determined homeostasis can be interpreted as an algorithm for minimizing the distance between target and observed outcomes and reveals a preference for outcomes closer to the target than others. It should also be observed that this form of behavior appears most often to be "wired in," i.e., affected by physical-chemical mechanisms, tradition, or other nonreflective devices.

In the second general form of adaptive behavior, explicit, as opposed to implicit, optimizing occurs. At a given point in real time, the agent perceives a set of feasible actions and selects a best member in this set according to an objective function or preference preordering. The perceived feasible set, or the objective function, or both, are then adjusted in response to experience. Several specific types of this general form can be distinguished, three of which are briefly summarized.

The behavioral learning algorithm. In this system of switches and rules (Day 1975), the rule governing behavior at any time is determined when a performance measure (outcome) belongs to the rule's associated switching set. A change in the performance measure sufficient to bring its value to a different level causes a change in action and a switch in the rule governing behavior. Simple examples can be constructed readily using four elemental principles of learning: (*a*) successful behavior is repeated; (*b*) unsuccessful behavior is avoided; (*c*) unsuccessful behavior is followed by a search for alternative action or modes of behavior; (*d*) search becomes more cautious in response to failure. Well founded in psychological theory and experimentation, models incorporating the first three principles have been the basis of the behavioral theory of the firm developed by Cyert and March. In Day (1967) and in Day and Tinney, it is shown that behavioral learning models augmented by failure response can converge to the traditional equilibrium for individual monopolistic or two agent monopolistic teams with stationary environments, though little is known about their performance in more complex settings. Recently, empirical evidence has been assembled that indicates businesses are actually governed by such rules (Crain and Tollison, undated).

We note that the behavioral learning model can be formulated as an extremely simple local or approximate optimizing of marginal variation in action based on extremely limited use of past results; formally, a simple recursive linear programming model. This brings us, then, to the second type of model based on optimization with feedback.

Recursive programming models. In these models, economic plans and behavior are represented by explicit maximizing models, such as linear, nonlinear, or dynamic programs, but with the assumption that actual outcomes are determined by additional forces unaccounted for in the individual optimizations. For this reason, the optimizations are in fact suboptimizations, as in the simpler behavioral learning case. These additional forces may act on the agent through environmental feedback, through estimates of current and forecasts of future states, and through behavioral rules that make allowances for future decisionmaking, that modify objectives on the basis of past behavior, and that limit change from established behavior as a tactic for avoiding uncertainty. Models of this type take a great variety of specific forms, examples of which may be found in Day and Groves and especially in Day and Cigno.

Adaptive programming or dual control. When applying strategic considerations to the problem of adaptation, the agent must account for all decision functions: observation, storage, processing, planning, and implementation. And, in choosing a course of action, he 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 that embody these considerations are called adaptive or dual control models and were originated by Fel'dbaum in a generalization of dynamic programming and stochastic programming techniques (Bellman). Extensively studied by control engineers, various examples have been described in several recent surveys; for example, Aoki (1977).

At this point, however, it is important to note the following. 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 rise more or less exponentially with the level of detail accommodated, so that the model in practice must be an extreme simplification of actual operating conditions. Even so, the method involves substituting a complex and extremely costly computational algorithm for real-time servomechanistic procedures, behavioral learning, or simple, tactical optimizing.

Now, if the decision-maker has something to learn about the structure of the environment, and not merely the value of certain environmental parameters, then one cannot be sure that sophisticated adaptive strategies will perform better than the simple tactics they replace. Whether or not and under what conditions they will perform better depends on the true environment and how stable the adaptive control model is when plans roll and knowledge evolves. Evidently, adaptive control models must belong in practice to the general class of optimization with feedback models representing bounded rationality.

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. 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 existence of slack to absorb unpredictable divergences between plans and realizations. 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 facilitates adjustment to disequilibria in commodity supplies and demands.

These mechanisms are visible hands, represented by specialized classes of economic agents, guiding and constraining transactions among firms and households. They are the conduit for market forces: they are the market, which is thus seen to be a collection of agents (bankers, brokers, salesmen, merchants, etc.) who must adapt more or less like producers and consumers.

The consequences of this conception of markets as agents mediating transactions in disequilibrium can only be guessed, for their derivation lies in the future, perhaps along lines begun in the promising work of Jean-Pascal Benassy inspired by the neo-Keynesian ideas of Clower and Leijonhufvud, and perhaps indeed certainly containing some of the ingredients from Forrester's industrial dynamics and his national economic model currently under development.

The instruments of government policy, like market mechanisms are exercised by agents (or agencies) who must likewise adapt to information feedback from the system as a whole. Government agents therefore perform according to procedures that are made up of the adaptive functions (observing, storing, processing, planning, implementing) and that are governed by determined homeostasis or explicit optimizing rules more or less like those operating in other economic spheres. It is thus not difficult to understand why economic policy, formulated and exercised as it must be by adapting humans, may merely add to instead of alleviate instabilities and inefficiencies already present in the system.

Salient Results

The adaptive approach has been the basis for a wide variety of modelling studies, and space limitations preclude even a brief synopsis here (though the interested reader may again be referred to Day and Groves and Day and Cigno). We must, however, survey some salient properties exhibited by certain models of this genre.

Inertia and Rapid Change

Static economic thinking often leads the economist 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 explicitly describe the inertia governing economic behavior. They explain how changes in any one short time interval are limited. Nonetheless, study after study has shown that with the passage of time quite drastic changes are brought about, even though short-run movements are modest.

For example, Cyert and March's behavioral duopoly model explained how an ex-monopolist's market share fell from 80% to 45% in about a quarter century. Other recursive programming examples explained the transition of backward regions or countries to a developed status with a massive migration of rural peoples to urban areas (Day 1968, Fan and Day) in the span of only a decade or two.

Explicit attention to disequilibrium 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 focuses on the accumulation of short-run, inertia-bounded changes out of equilibrium. The impression obtained from this point of view is one of great and often rapid change after only a few years. Certainly, a generation, and often even a decade, is adequate for producing pronounced alterations in commodity patterns and production technology, even though change at any one time appears to be sluggish.

Now, change produces many "externalities." People are required to accommodate themselves to changing occupations, changing locations, 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.

The consequence is severe, short-run but persisting adjustment problems. It may well be that much less attention should be paid by policymakers to accelerating adjustment and much more attention paid to controlling its speed and diminishing its costs.

Phases of Economic Change

The picture of economic activity which adaptive models often 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 by the stage-making theories of economic history. Rather, they come in a variety of orders and types that depend on the initial technological and behavioral conditions of the economy in question. They also depend on the economy's peculiar parameters of geography, technology, and culture.

Disequilibrium Trajectories

A consequence of the multimode, multiphase, overlapping wave character of solutions to adaptive models is that solution trajectories often exhibit trends that reverse themselves and have the character of moving away from their final equilibrium values or trends much of the time or perhaps even almost all the time until some threshold or watershed period is reached. If this is also a characteristic of real economic systems—as I think it is, then it means that information about the past behavior of such systems available at any given point may deceive one as to future system performance. In this case econometric methods based primarily on fitting single phase systems of equations derived from equilibrium theory to time series data would provide extremely misleading forecasts of future directions of change in the system.

Natural Resources Policy

The physical durability of natural resources imposes a dynamic structure on resource allocation more or less analogous to that imposed by the durability of capital goods. Resource economics therefore requires dynamic analysis. We can, of course, extend to this field the basic concepts of equilibrium, recognizing that time adds a new, essentially infinite dimension to the characterization and existence of equilibrium. Using appropriate tools (optimal control, differential games, Hamiltonian dynamics), the past or future can be described as an optimal trajectory, as, for example, in Vernon Smith's imaginative rationalization of the Megafaunal extinction.

As much as these and other superb examples of good economics are to be admired, they cannot be followed blindly in erecting the economics of natural resource policy. Too many issues fundamental to the formulation of such policy are entirely glossed over by these contemporary, dynamic embodiments of neoclassical, equilibrium thinking. Among these fundamental issues are three upon which I wish to comment here: the problem of intergenerational exchange, the problem of overshoot, and the problem of surprise.

Intergenerational Exchange

The first point to be considered is that all economic transactions in reality are among members of the existing population. None involve agents not yet brought to life. Current decisions will come to constrain those not yet born and they may be based on farsighted plans, but the agents who make them are unlikely on the face of it to be able to generate decisions that lie on optimal trajectories even if they can be properly defined. Defining them properly, when we recognize that agents die and their numbers and organization evolve, is a matter that raises questions of a morally profound and scientifically baffling nature that are just beginning to receive attention. Certainly the comparability of the utility of agents of differing generations, implicitly assumed in applications of dynamic optimization, has got to strain the credulity even of Frank Ramsey's most ardent admirers when it is applied to the generational exchange problem involved in natural resource allocation. But it is possible that farsighted planning, combined with time preference, is a necessary precondition for growth, while having as its inevitable consequence the rapid exhaustion of resources and the imposition of declining fortunes for some members of the present and future generations. This is a conjecture whose theoretical analysis should have an important bearing on how we analyze resource policy.

Overshoot

If the current generation of economic agents does not know what the equilibrium trajectory is, or perhaps even how to define it properly, and if the dynamics of the system as a whole is strongly influenced by rules of behavior, then it is possible that population and levels of well-being sustainable for long periods of time will be exceeded, then followed by a fall in numbers and a perhaps rapid decline in wealth.

This is the spectre raised by the doomesday or neo-Malthusian Cassandras using models of an essentially adaptive character. Its credibility, however, need not be based on a particular adaptive model but on the historical and archeological record. Many cultures and their associated economies have passed away, driven from existence by their more successful competitors, as we see today in the final destruction of primitive peoples or by their internal (necessarily adaptive) resource allocation mechanisms, as has been speculated to have been the case in the classic Maya collapse (Culbert).

Surprise

To sum it all up, adaptive models lead us to expect surprises in the evolution of economic activity whose exact timing and magnitude defy prediction (for otherwise they would not be surprises). Instead of focusing on economic efficiency, policy should perhaps be aimed at preparing for surprises, not predicting them—which is a contradiction in terms. The way this is done in individual living organisms (Canon), in animal and primitive human societies (Wynne-Edwards), or in complex business firms (Cyert and March) is to allow for slack, which, in essence, means surplus resources, redundancies, or less than maximal growth.

An example that has been used in this century is the maintenance of surplus stocks for stabilizing agricultural prices. The costs in terms of reduced efficiency lead to attacks on, and indeed a reduction in, the use of this mechanism. But the absence of stocks may lead to severe hardships in the future, just as overproduction in the Sahil has led to the exhaustion of surplus grazing resources with catastrophic implications for the dependent populations.

Another way surprises are prepared for is through knowledge: the accumulation of facts, theories, and operational methods that may be used to generate new rules of behavior, new forms of organization, new chemical and biological processes, new physical mechanisms for controlling the environment when and if they are needed or desired. Certainly the attempt to discover and apply new knowledge can be induced. The knowledge to be accumulated as a defense against surprise, however, surely cannot be induced by surprising events—another contradiction in terms. Instead, that kind of knowledge must be pursued without a goal, without identifiable economic motive just as, according to evolutionary theory, the planning mind itself is generated without a plan.

A Final Comment

A basic principal of survival for the adapting economy must surely be to learn from the past—for it is the only way to learn—but allow plenty of room for surprise. The way to allow plenty of room for surprise is to conserve resources and to create knowledge.

Possibly, and I do not think it impossible, the best way to conserve resources and create knowledge is to allow market forces (recognizing that they work out of equilibrium under the control of adapting agents) to allocate natural resources as best they can and accept the associated costs: the destruction of primitive cultures, the accelerated extinction of many nonhuman species, natural degradation, and the mad pursuit of Philistine values, for these costs may be lower than those imposed by further economic engineering.

Possibly instead, and my instincts as well as my intellect side with this view, the best way to conserve resources and create knowledge is not yet known and will require economic invention and engineering of a high order of sophistication involving the role of the intellect in the evolution of humanity and its forms of organization. If this is so, it will surely involve the development of new institutions for maintaining slack and new forces for motivating present decisionmakers to endow themselves and their descendants with unexploited or embodied natural resources and a knowledge of the past. This accumulation of historical knowledge has brought humanity where it is now, and only with the future accumulation of both resources and historical knowledge can mankind's further evolution be assured.

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