PAPERS on Economics & Evolution

0514

**Microeconomic Foundations
for Macroeconomic Structure**

by

Richard Day

Microeconomic Foundations for Macroeconomic Structure

Richard H. Day

Department of Economics

University of Southern California

Los Angeles, CA 90089-0253

Abstract

The models used in economic theory, though necessarily abstract, should be consistent with the nature of decision making behavior. A formal metaphor of individual behavior as a continuous flow indicates certain requirements that theories of consumer, producer, and economywide behavior should exhibit. A family of discrete time, recursive optimizing models is suggested as the appropriate building block for further developing dynamic economic theory.

> Whenever there's an occasion to go back to the
> fundamental conceptions on which any
> science rests, and to formulate them
> with accuracy, we almost always
> encounter difficulties . . . .
>
> Augustine Cournot[1]

1   Introduction

Macroeconomic theorists have rightly emphasized the importance of microeconomic foundations, for it is obvious that a theory of the whole economy which is inconsistent with the character of its constituent parts must be misleading and possibly dangerous if it were to justify policies whose effects were different than those intended. The remarks that follow describe what seems to me to be essential features of human behavior, especially those aspects involving rational thought and economic activity that are characteristic of much current microeconomic research including the contributions to this conference and with which higher level theories of households, firms, markets, and aggregative economies should be consistent.

Although controlled experiments play an important role in the accumulation of knowledge, introspection and close observation of those around us are sufficient to reveal universal attributes of rationality and economizing behavior.[2] These attributes are discussed in sections 2 and 3, followed in section 4 by a discussion of discrete time modes of economizing and behavior that are here proposed as the appropriate foundation for higher level theorizing. Sections 5 and 6 provide some brief formal notes that describe the crucial regime switching character of behavior in continuous time, a general class of adaptive economizing models, and an abstract, economizing society. The paper concludes in section 7 with a brief admonition.

In commencing this undertaking I have tried to start from scratch—not in the sense of ignoring previous theory—but rather by trying to describe

---

[1] Cournot (1963, p. 14).

[2] The knowledge one may be garnered in this way can be significantly enhanced by our own classic economic literature, but even more so by reference to the world's great literary and philosophical works whose greatness rests in part on the insights they offer into human thought and behavior.

and formalize behavior at a more elemental level and then see if and how the concepts of economics need to be modified to serve better the purposes of science and policy that motivated their development in the first place. Explicit mention of some concepts with which each of us is intimately familiar would seem to be superfluous. But I believe it is a chore necessary to re–establish contact between economic theory and the subject matter it is intended to illuminate.[3]

2   Rationality

2.1   Rationality, Irrational and Nonrational Behavior

For the present discussion let us agree that rationality is the capacity to exercise conscious, systematic, logical thought including the careful identification of things, the perception of causal relationships among them and the construction of logical procedures for solving problems or deciding among conceivable plans and actions.

As defined, rationality is a property of thought not of action or of outcomes. It is also not a property that can be ascribed to a group or a nation except when members agree on coordinated action that has been arrived at rationality. Simon (1978) uses the term 'instrumental or procedural rationality' for rational thought as defined here.

Not all conscious thought is rational, indeed, perhaps most of it is not. Once a problem has been solved or action induced by rational choice is underway, the mind might be occupied by all sorts of thoughts until the object of the action or sequence of actions has achieved the objective or until a new problem is conceived. Between periods of rational activity the mind may be absorbed by nonrational or irrational day dreams, reveries, reminiscences, religious exercises, some form of entertainment, conversation, argument, or actions carried out by rote or habit.

Unconscious thought may have a rational basis as is sometimes the case when conclusions or actions are based on intuition. In such cases, a problem solution becomes conscious through a kind of revelation, which may then be

---

[3]It is worth quoting Mannheim, a fellow academic at this point: "Academic [concepts] tend to become sterile because they fail to take cognizance of the world outside academia." (Mannheim (1936, p. 73)).

shown to be rational, as in Poincaré's famous description of mathematical discovery.[4] More generally, any action whose outcome can be shown to be consistent with a rational process of determination is referred to by Simon as *substantively rational.*

2.2   Rationality is 'Local'

Thought always has a local character, that is, it is never about everything. It is always conditioned by the current state of mind: one's current knowledge, level of intelligence and perceptions, emotional state and focus of attention. To put it negatively, rational thought is constrained by ignorance (the limited knowledge of the relevant), by stupidity (the inability to perceive correctly or derive logical implications of known facts or principals), by myopia (the limited ability to anticipate consequences), by egoism (the inability to account sufficiently for the preference and actions of others), and by immaturity (the experience dependent, developmental character of knowledge and preference). As these limitations are always present, it goes without saying that rationality is 'bounded.'[5]

2.3   Strategy, Tactic and Lifestyle Paradigms

Let us distinguish between two types of rationality: one considers overall patterns of behavior and one focuses on detailed actions that effect part of a given pattern. The former may be referred to as *strategic*, the latter as *tactical*. Paraphrasing dictionary definitions, a strategy is a plan for one's overall kinds of activity that accounts for one's environment and interactions with others. A tactic is a specific action procedure or sequence of actions for carrying out a strategy. Once adopted, a strategy constitutes a constraint that focuses rationality on concrete steps intended to advance the overall plan.

A strategic plan is seldom—if ever—thought out as an 'open loop' trajectory of specific actions that will be followed 'forever.' Neither does rationality

---

[4] "Mathematical Discovery," Chapter 11 in Poincaré (1952). Art, literature, and religion all provide examples of an analogous process by which a form, story, spiritual or moral concept suddenly springs into the conscience accompanied by a sense of beauty and a certainty of its truth.

[5] Thus, the phrase 'bounded rationality' is superfluous in characterizing human thought.

4

often—if ever—arrive at a 'closed loop' rule that determines once and for all one's tactical reaction to every contingency. Rather, strategic plans often involve more or less 'vague stories,' 'lifestyles,' or patterns of behavior and possessions that one would like future actions to bring about. For want of a better term, let us refer to such stories, lifestyles, or patterns as paradigms.[6]

What people do is as important as what people have, and what people have and use is driven by what they do. Indeed, the concept of a lifestyle paradigm involves a way of life made up of patterns of activity involved in work and leisure and lists of generic goods appropriate for a given lifestyle.[7] The analogous interpretation business is a firm's strategic plan that outlines the general objectives for future attainment in terms of product development, capacity expansion, managerial reorganization, etc. The input/output structure of activity establishes the technology for satisfying needs and wants for individuals and strategic objectives for firms.

Paradigmatic choices are not always economic in nature for, as is often the case, they are not constrained by resources, money, or even time but only by imagination and intelligence. Instead, paradigmatic choices frame behavior by narrowing down the problems of a prospective lifetime. They do this by posing a limited class of 'less' strategic and tactical choices distributed over time that will be involved in effecting the chosen paradigm. Thus, paradigms and strategies decomplexify the overall problem of how to live one's life or run one's business into a sequence of simpler problems, each one of which need be considered only after its predecessor has been solved: it will be dealt with 'when the time comes.'

---

[6]I have not seen this point of view in works of economic theory but have come across related arguments in philosophical writings, John Dewey (19xx), for example, and after writing this passage, Bratman (1987).

[7]A somewhat similar distinction between strategic paradigm and tactical decision was made by Herrnstein and Prelec (1991) who, on the one hand, refer to *distributive choices* as those that involve 'bundles' of decisions that may be distributed over an anticipated future and, on the other hand, choices that result in immediate action. Strategic choices in our case are distributive choices in their sense. Our concept is intended to be more general including, in effect, choices among potential but more or less vague stories or potential autobiographies that then focus or constrain tactical choices to ones designed to make those stories come true.

2.4 Wants and the Characteristics of Activities and Goods

Wants and needs derive from neurophysical processes that underlie the formation in the mind of preferences among alternative actions and goods. Sooner or later activities and goods necessary for survival become needs driving action. The mind also develops wants based on physiological, aesthetic, intellectual, spiritual, or egoistic thoughts and feelings. Regardless of their origin, wants can usually be satisfied by alternative activities and or goods.

Economic development over the centuries has led to an expanding array of goods available to satisfy needs and wants and, indeed, the mere existence of a good—especially a new or novel one—may engender a want for it. It may be said that *wants evolve with goods*. This implies that a good manifests various characteristics so that in terms of characteristics, activities and goods are variables, as in Chamberlin (1953), that vary along a many faceted, multidimensional space of attributes, as in Lancaster (1971).

Given this complex of relationships among wants, attributes of goods, and activities, consumers' choices about what to buy, and producers' choices about what to produce would be hopelessly complex if one thought about all the possibilities at any given time. A stalemate is overcome by localizing one's consideration on the basis of one's limited knowledge, experience, and more particularly on the basis of one's currently adopted lifestyle paradigm or strategic plan, and its subsidiary strategic commitments. Moreover, because lifestyle paradigms play such a strategic role in behavior, producers frequently package their products in terms of the characteristics that are associated with such paradigms.

2.5 Contingency, Learning and Adaptation

Rational behavior need not be substantively rational. That is, the premises given to the rational process, one's conscious knowledge of internal and external states and of the causal relationships among them may have been mistaken. Unanticipated changes in circumstance force adjustments in response. Failing to derive a viable action, events will force the occasion; the individual must then solve a new problem; one does what one can; finally, one accepts one's fate. Such is life as we live it.

If a failure occurs, it may be necessary to adopt a new paradigm—or,

perhaps, less dramatically, one may repeat a tactic or adopt new tactics to overcome the hurdle. All along the way experience accumulates, new options arise, knowledge advances, one's preferences change, one's skill in carrying out intended rational actions improves. In short, learning occurs and states of mind that condition thought evolve. Early on in life paradigms may be vague and strategic choices short sighted. Later, new life styles may be considered (not every little boy's desire to be a truck driver or fireman will be retained). Longer range plans emerge involving more complex tactical actions based on a wider perspective.

Assuming that chance is ruled by probability, economic behavior of individuals is explained by probabilistic laws similar to those used by insurance companies which require the input of trained actuaries in their management. An alternative hypothesis of behavior under uncertainty is based on the concepts of caution and daring. This hypothesis asserts that individuals often or usually begin with the situation 'where they are' and consider changes that are not too far removed from this reference point or, rather, that are close enough to it. Individual 'risk preference' is reflected not in terms of expected utility but in terms of a semi–metric or 'danger distance' that quantifies how far removed any given alternative potential action is from the reference. One's degree of caution or daring at the time is then represented by the maximum distance one is willing to go in pursuit of preferred alternatives. It defines a safety zone or zone of flexible response within which choices are considered to be safe enough and within which one acts as if one were certain. When one's present situation is perceived to be untenable, the safety zone may define a minimum (safe enough) distance *away* from the current operating point. Thus, the threat of bankruptcy triggers drastic attempts at reorganizing activity and its financing. If within that zone a change is made, the subsequent zone will be centered on the new choice just made. The result is a variation of trial and error search.

A closely related concept used in early econometric models of investment, that of *partial adjustment*, which represents an action as a weighted average of the optimal solution to a current optimization problem and one's past behavior. The rationale is based on the idea that one should try to determine the best choice one can, but be cautious in adapting to it as a hedge against the chance of 'going too far' and making matters worse.

2.6   Priorities and Satisficing

A common way of simplifying choice problems is to arrange needs and wants in a priority from most important or highest objective to least important or lowest objective, attending to the highest objective first, then, assured that it is satisfied, taking up the next, and so on until no more scope for further choice according to less important goals remains. This common device for exercising rational choice rests on the construction of a hierarchy of preferences or strategic objectives and a criterion of satisfaction for each that, when reached, triggers consideration of the next preference ordering or objective in the hierarchy.[8]

Prioritizing preferences is typical of decision making, not because people are not rational, but because they are! They know this is often the best way to be effective in the exercise of rational choice. Those who can not prioritize are often mired in quandaries, unable to 'sort things out,' unable to commit themselves to objectives.

Note that such lexicographic procedures imply a sequential, narrowing down behavior very much like and indeed related to and including the organization of thought into strategic and tactical components. A first priority is to find an action that works. A second priority is usually to find one that is safe enough.

2.7   Imagination

In the exercise of rationality the imagination plays a fundamental role. It constructs the problem to be solved. Solutions of previously solved problems can simply be remembered and applied. To be solved rationally, new problems cannot merely be perceived: they must be formulated or conceived in the imagination. All imagination is creative in the sense that one must imagine outcomes of choices not made before or at least not made in one's current circumstances. Everyone possesses this faculty to some degree but clearly the scope of one's rational considerations varies greatly among individuals. Some are willing and able to imagine wide ranging alternatives while others may be unwilling or unable to think of more than a few more or less

---

[8]For a profound development of the theory of preference on the basis of needs and wants and their arrangement in a lexicographic order, see Georgescu–Roegen (1954) or (1961, Chapter 3).

already familiar options.

By *creative imagination* we mean something more: the conception of potential activities and or objects that are entirely novel to that individual, and which may tax the individual's capacity to transform that which has been imagined into actual acts and objects. The greatest genius is characterized by both attributes to a marked degree: both creative imagination and extreme competence in solving the problems involved in changing the material world and/or influencing other people's thoughts about it.

3   Economizing Behavior

Economics is the science of applied rationality par excellence, that is, rationality applied to the problems of determining how hard to work, how to allocate income and wealth among alternate consumption and savings possibilities, what and how much to produce, and how to produce it. This science has led to highly stylized theories for households and firms in decentralized market economies and for centralized planning in socialist states. In practice rational choice involves consciously identifying constraints, enumerating and comparing alternatives, specifying one's preferences or profit objectives, then determining an optimal choice among those considered.

Much (perhaps most) economizing behavior, however, seems to be initiated without the help of this process.[9] Rather, when and if it occurs, it seems often to be governed by different but related processes including: (i) motivated search, (ii) imitating, (iii) obeying an authority, (iv) following a habit (habering), (v) following a hunch, and (vi) unmotivated search. Let us consider how these alternative modes of economizing behavior are related to rationality.

Motivated search, that is, experimentation or trial and error involves trying two or more actions (one after the other, of course,) and choosing subsequent actions in reference to the consequences of these trials. This mode would seem to be most closely related to explicitly rational choice because the actual solving of constrained optimization problems requires a mental

---

[9]Compare Schumpeter (1951, p. 128), "...the great mass of our everyday actions is not the result of rational reasoning on rationally performed observations, but simply of habit, impulse, sense of duty, imitation, and so on, although many of them admit of satisfactory rationalization *ex post* either by the observer or the actor."

or computational trial and error search algorithm in which each step in the search involves a relatively simple, local and approximate optimization problem that may or may not be in the right direction, then responding to success or failure by modifying the search appropriately. Experimentation, however, differs from computational algorithms in that each step is not just a thought or computational iteration, but a real action whose success or failure is actually experienced. Given the limitations that circumscribe rationality, *explicit optimizing*—no matter how sophisticated it is—is in reality an experiment: always local, always adaptive, always a trial subject to error. Conversely, every experiment involves a rational process in its thoughtful comparison of past outcomes, its determination of a direction of search, and how far to go in any direction. Thus, motivated search is an adaptive, rational process.

Imitation is clearly invoked frequently in choice situations and involves doing—or trying to do—what someone else is doing. Refer to that someone as 'the model.' This, however, involves rational thinking in another guise, for given some sort of 'metric' that indicates how 'close' the imitator is to the 'model,' the problem is to minimize the 'distance' or to maximize the 'closeness' to the model, subject to the constraints that limit the choice made for oneself and to the further condition that the imitator's preferences are the same as the one imitated. Still, adapting one's own decision to that of the model may get one much closer to a good solution than if one decided completely on one's own. This potential helps explain the generation of fashions and herding. The lags in adoption that are distributed among imitators is explained by the confidence one has in the model. The more people have adopted a given successful course of action, the more confidence potential imitators have in following.[10]

Following an authority is often involved when the follower has greater confidence in the judgment of the authority than in oneself or, contrastingly, in order to avoid punishment which can be meted out if one is disobedient. This mode may involve challenges to rational thought for one may not be

---

[10]Quite coincidentally I was rereading Machiavelli while thinking about this paper and came across his more literary way of putting it: "*For men almost always follow in the footsteps of others, imitation being a leading principle of human behaviour.* Since it is not always possible to follow in the footsteps of others, or to equal the ability of those whom you imitate, *a shrewd man* will always follow the methods of remarkable men, and imitate those who have been outstanding, so that, even if he does not succeed in matching their ability, at least he will get within sniffing distance of it." (Machiavelli (1988, p. 19)).

capable within one's own constraints of obeying, or if capable, only of succeeding after thinking through the necessary steps that will be involved. But even then, the difficulty of rational choice is reduced by not having to figure out *what* to do but only *how* to do it, and here again imitation will often be relied on.

Haberation or following a habit is to repeat without conscious thought what one has done before in the same situation. In the normal course of living, a growing fraction of one's life is governed by habit as one matures. This is explained by the fact that habits arise from the experience of successful action, ones that accomplish what was intended. In short, habits are the result of learning what actions work and what ones work best in repetitive situations. They contribute to the economy of mind by reducing the number of choices which one needs to consider consciously.

A successful action based on *intuition* or *hunch* would seem to be the result of subconscious rationality in the sense that the outcome is apropos. For example, success of a business action taken on a hunch establishes its rationality *ex poste facto*. Successful entrepreneurs, managers, and speculators often seem to be generously endowed with this kind of acumen. It would seem to be akin to Poincaré's subconscious process that propels correct new theorems into the consciousness accompanied by a certitude that they are correct, but whose correctness is only established mathematically later. In the case of the shrewd business decision a sufficiently complex optimization model should reproduce the intuition, but think how much expense is saved by the hunch!

Unmotivated search involves action impelled by thoughtless impulse that has no apparent basis in explicitly rational thought or in the other modes of economizing behavior. It seems to be arbitrary, erratic, without purpose, irrational. Why does such behavior take place? The study of this question (by Gary Becker or Shyum Sunder) is of at least peripheral interest to economists, for it has been shown that random choice within a market framework can exhibit some of the properties of choices made rationally. An ethnological answer may lie in a property all mammals share, that of necessary fluctuation of activity and a certain need for changing action even when no needs or wants seem to be driving it other than an aversion to boredom. Of more relevance to economists is the role of randomized search in complex environments, as in George Box's evolutionary operations procedure (EVOP) or in Holland's simulated annealing algorithm. It may be a device to get a

search started when one hasn't a clue what to do or where to go. Or, it is useful to perturb one from an already adopted locally best optimum when other possibly better local optima may exist.

In any case, these alternative modes are generally exercized sequentially, each step along the way limited to a relatively small number of variables whose relevance is determined by previous paradigmatic and higher level strategic choices already made, and by where the decision maker is in the hierarchy of preferences that form as one goes along. If one of the actions fails when carried out, a new tactic or strategy, or even a new paradigmatic choice must be formulated. But how foolish it would be to base life's choices on a strategy determined once and for all when one is young, before much experience has been accumulated, and before one's preferences are more fully formed. It is true that humans sometimes adopt a way of life based on the repetition of a stable pattern of behavior and eschew consideration of new information and new ways of acting. Still, our minds are so constructed that, in response to crucial types of outcomes, learning is reinitiated and search resumed, just as computer algorithms do when the parameters of the problem to be optimized are perturbed. It is this capacity that constitutes the extreme adaptability of humans to different or changing environmental conditions.

The histories of associated individuals, however, may be similar, precisely because most people do behave like others of similar psychological, sociological, economic and geographical attributes. Imitation of successful others and the following of others who have authoritative standing is sufficient to explain this, and such imitation and following is seen to have a rational basis. Anyway, the interest of economics is ultimately not about individuals at all but about aggregates of them. That is why economic theory is usually formulated with reference to aggregates of individuals as in the household, firm, or whole economy models. If the aggregative models are decomposable *in principle*, then economizing may be effectively modeled for most scientific and policy purposes as a discrete time, sequential optimization processes that represent the behavior of aggregates constituted of appropriately similar individuals, households, or firms.

To summarize, decisions are contingent on both internal, subjective conditions and on external, objective conditions. As the processes of living and thinking proceed, the effectiveness of strategic and tactical choices may improve. In any event, it is universally true—and we can put it as an axiom of

any scientific theory of economics that *rationality is always and everywhere local and adaptive.* Moreover, among the implications of of all this is that behavior in continuous time (i) is broken into intervals, some of which are governed by a specific mode of economizing behavior, (ii) which switch at intermittent intervals among possible modes, (iii) periods of rational decision making are separated by periods of nonrational behavior and *this happens every day*, and (iv) trajectories of behavior will be characterized by multiple phase dynamics with evolving preferences where the various equated constraints and specific preference ordering in the order of priorities and specific orders of priorities at each time may vary among the agents from time to time. Consequently, the qualitative as well as the quantitative history of each agent may be unique.

4 Modeling Adaptive Economizing

4.1 The Fundamental Modeling Problem

Rational economizing behavior as outlined above involves choices formed as life style paradigms, hierarchies of strategic plans and specific tactics arranged and determined sequentially, formulated and reconstructed on the basis of accumulated experience, knowledge, and competence. Action involves preferences for alternative sequences of activities that make up segments, as it were, of life style patterns which require various goods used or possessed. Outcomes are often uncertain and action constrained by a sense of caution. Wants are ordered or prioritized, and choice is determined sequentially by one among several alternative modes of economizing. Different individuals may use the seven specific modes of economizing with greater or lesser frequency but all are exercised by most throughout life.

Given the complexity of behavior implied by the modulation of behavioral and economizing modes, modeling the continuous flow of actions into economic theory would involve excessive if not mind numbing complication. But every behavior mode, rational or otherwise, is initiated at discrete intervals. This fundamental, regime switching nature of behavior suggests a natural reduction to a sequential process of economizing involving activities, *not in all their details and frequency of occurrence*, but exploiting instead aggregations of them that would in principle be decomposable into their detailed compo-

nents and executable in turn within a given finite interval. These intervals not only may aggregate an entire sequence of activities that are in fact carried out over a finite period. They will also subsume or ignore altogether the very large number of nonrational actions that will inevitably be interspersed in reality within the period chosen for economic analysis, be it a month, quarter, year, or generation of quarter century. Action is then modeled as an average flow rate throughout the discrete period (month, quarter, year, or generation).

4.2   The Recursive Programming Approach

The mathematical analog of this conception of adaptive economizing is recursive programming, which consists of a sequence of recursively connected constrained optimization (mathematical programming) problems for which some of the parameters of each problem in the sequence depends on the solutions of past problems in the sequence and possibly endogenously generated states and exogenous variables. The general class of such models encompasses a variety of theoretical and applied examples including virtually all algorithms for solving static and dynamic constrained optimization problems, decentralized planning algorithms for large scale complex organizations or socialistic economies, discrete time market tâtonnement mechanisms for general equilibrium models, and adaptive games.

When used to model adaptive economizing processes, such models are not 'backward looking' but rather each problem in the sequence characterizes the formulation of a potential future action that is about to be or is taken, or a sequence of anticipated actions associated with imagined future periods, the first one of which will be implemented. In the latter case, a description of rationality requires two time indexes, *anticipation time* representing future time periods, and *historical time* representing the current period for which imminent action is to be determined. In such a case, each decision problem in the sequence has the structure of a dynamic programming problem which may satisfy Bellman's equation *in anticipation time index.* The 'intertemporal optimization' can in principle then be reduced to a current present period optimization in historical time but one that implicitly takes account of a finite or infinite number of future periods.

In the pure deterministic, dynamic programming case no connection with past actions is incorporated because the intertemporal structure in antici-

pation time is (implicitly) assumed to incorporate perfect knowledge of all relevant connections between actions and states. No distinction between anticipation time and historical time need then be incorporated. Nonetheless, such models of any complexity must be solved by algorithms that fall in the RP class. The same can be said of the pure stochastic, dynamic programming case as used in much of the macroeconomic literature of the Lucas/Kydland/Prescott type. In Bayesian Dynamic Programming, however, where the dynamic structure of the real process is assumed to be known but the parameters unknown, a recursive, dynamic programming structure emerges as each stochastically influenced outcome of the immediately past historical period is incorporated in the new Bayesian optimal estimate of the next anticipated action. The *dynamic structure of such a decision formulation, however, does not, nor ever can be based on the true dynamic feedback structure of the actual environment of the decision maker*, not because that environment is stochastic but because it is always represented by incomplete knowledge based on estimation and approximation.

In very special decision problems where potential interactions between the specific environmental conditions and the controls to be determined can be represented with great accuracy, the methods of dynamic programming are extremely useful. Such problems arise in engineering contexts where physical processes are well understood and exacting description and control is possible. For example, in guiding a manned spacecraft to the moon dynamic programming could in principle provide an optimal strategy if the assumptions of Newton's equations were themselves exact. But they are not. Thus, the earth is slightly pear shaped. It is not a mass point but an extensive object with heterogeneous density. So called perturbation terms must be incorporated in the mathematical model of space flight to provide for these complications. The fact that they are approximations means that the dynamic programming problem must be reinitialized at intermittent intervals to give accurate projections. This requires incorporating information exogenous to the mathematical model itself, by providing for an independent source of data from the environment about the actual position of the craft so the approximate, endogenously generated prediction can be reinitialized before the departure from the 'optimal' path leads the crew astray. This is the case even if no random perturbations at all impinge on the system.

It seems to me, we can put it axiomatically: wise persons—no matter how intelligent—will never hold themselves hostage to an 'optimal strategy,'

however cleverly formulated without providing tactical rules to take account of exogenously determined information as it becomes available.

The current emphasis in macroeconomics and finance on dynamic programming models is rightly motivated by the relevance of thinking about the future in order to determine what to do in the present, but the theory is wrongly based on the Bellman assumption that the fundamental recursion is from future to the present and for which the past matters only as an initial condition and is otherwise an irrelevant bygone. In the 'recursive programming approach' the fundamental recursion is from past to present so that what is planned for the future and what happens in the present grows out of history. Note here that the same recursive properties exist for temporary equilibrium as is brilliantly expounded in Grandmont (1988). However, each point in the sequence of temporary equilibria presumes the existence of an implicit tâtonnement type equilibrating map that makes all the decisions of the several agents compatible for each current period, one after the other.

The RP way of theorizing about rationality originated with Cournot, Walras, and Marshall: Cournot with his recursive best response adjustment process; Walras with his consumers and producers tâtonnement (when modeled in discrete time); and Marshall with his incremental consumer choice and quasi–rent dynamics of the firm.

In general such models represent behavior or algorithmic computations by sequences of recursively connected, local, approximate, or behaviorally conditioned optimizations. The recursive connection is determined by a feedback structure which need not be completely incorporated into the specification of the optimizing operator. The latter property, which distinguishes most recursive programming solutions from intertemporally optimal behavior, is based on the fundamental premise that real world economic computation and behavior proceed by decomposing large complex decision problems into smaller, simpler, approximate or local decision making problems that may anticipate future potential actions but that necessarily react to feedback from the only partially understood environment.

Because the general class of recursive programming models includes virtually all optimizing algorithms, including decentralized decomposition of economizing decisions in organizations and entire economies, as in Walrasian tâtonnement, and, at the other extreme, adaptive economizing as in the

Fisher/Leontief model of growth in the Robinson Crusoe world,[11] it forms a canonical form for dynamic economic theory. A general class of RP models is outlined in §6.2.

4.3   Learning Implies Rationality

An objection to using *any* representation of explicit optimizing—adaptive or otherwise—is sometimes raised by those who become acutely aware that much, if not most, behavior does not involve an explicit consideration and comparison among a set of perceived, evoked alternatives. To abandon the idea, however, is tantamount to abandoning learning as well, which always involves a comparison of outcomes of alternative actions and a search for actions that improve consequences. As recognized in the discussion of non–explicit optimizing behavior, the modes of adaptive economizing behavior have a rational basis in the sense of economizing decision costs which include costs of data gathering, correctly formulating or adequately approximating the choice problem in all its relevant dimensions and comparing alternative solutions so cleverly as to learn the best among them. The facile representation of optimizing problems mathematically obscures the magnitude of *representing* real world alternatives which—even for trivial items of food and clothing—can involve considerable time and expense.

5   Behavior in Continuous Time

To fully appreciate the problem of characterizing optimal or even nonoptimal behavior in continuous time, it is helpful to formalize the idea abstractly. Then the use of adaptive economizing in discrete time becomes a natural device for constructing dynamic economic theory.[12]

5.1   Agent–Environment System

Begin by identifying the state of the agent's environment by a vector, z, belonging to an environmental (external) state space, $\mathcal{Z}$, that accounts for

---

[11]Leontief (1958).

[12]This section is taken with slight amendments from Day (1995).

nature and all the other agents—which are not represented explicitly. Suppose the agent can be described by the triple of vectors, (a, m, s), where the *action*, a, represented by the intensities with which the agent's various activities are being pursued, the vector, s, represents the physical state, and m, the state of mind of the agent where $a \in \mathcal{A}, m \in \mathcal{M}$, and $s \in \mathcal{S}$. We refer to $\mathcal{A}$ as the *action space*, $\mathcal{M}$ as the *mental space*, $\mathcal{S}$ as the *physical space* of the agent at a given time, and the pair $(m, s) \in \mathcal{M} \times \mathcal{S}$ as *agent state*.

Actions, motivational states of mind, internal states of body, and external states of environment are very general and inclusive concepts. Actions include both physical and mental behavior such as sitting and reading, operating a lathe, making up a shopping list, flying an airplane, deciding which television show to watch while doing dishes. Internal states include neurophysiological conditions, or, thinking of the agent as a consumer or firm, stocks of physical goods 'inside' the household or firm. External states include all relevant aspects of the physical environment and of all other agents.

The agent's action through time is represented by an action map, $\alpha : \mathcal{M} \times \mathcal{S} \rightarrow \mathcal{A}$,

$$a(t) = \alpha\Big(m(t), s(t)\Big). \tag{1}$$

Behavior must be compatible with the internal and external environments, a requirement represented by the *potentiality correspondence*, $A(s(t), z(t))$, and the inclusion,

$$a(t) \in A\Big(s(t), z(t)\Big), \tag{2}$$

which represents the conservation of energy and material flows in the passage between agent and environment and, more generally, various technical, psychological, and social constraints that limit the range of action.[13] Assume further that changes in mental, physical, and environmental states are governed by the equations

$$\dot{m} = \mu(a, m, s), \tag{3}$$

and that internal states and external states are transformed according to the differential equations

$$\dot{s} = \sigma(a, s, z). \tag{4}$$

---

[13]Evidently, an agent state, (m, s), recognizes a mind/body dichotomy which still offers a challenging puzzle for neurophysiology. Even if m cannot exist without s, it seems equally evident that m emerges from s and functions in a sphere of its own which we call the mind. That is, s belongs to the realm of thought whatever it is. Thus, the brain is a structure mediating chemical and electrical processes. Mind is what the brain does.

$$\dot{z} = \omega(a, s, z) \tag{5}$$

where $\dot{m}(t) = \frac{dm(t)}{dt}$, $\dot{s} = \frac{ds(t)}{dt}$ and $\dot{z} = \frac{dz(t)}{dt}$. A finite agent–environment history of duration or life span, $t_\ell - t_0$, is a vector function of time, $(a(t), m(t), s(t), z(t))_{t=t_0}^{t_\ell}$, that satisfy (1)–(5).

The existence of such a history depends on the compatibility of the system components. Let F define the *amenable situations* for which there exist feasible actions:

$$F := \Big\{(s, z) \in \mathcal{S} \times \mathcal{Z} \mid A(s, z) \neq \emptyset\Big\}.$$

Given these definitions, an agent–environment history exists if and only if the *situation is amenable*:

$$\Big(s(t), z(t)\Big) \in F, \; t = t_0, \ldots, t_\ell,$$

and *behavior is practical*:

$$\alpha\Big(m(t), s(t)\Big) \in A\Big(s(t), z(t)\Big), \; t = t_0, \ldots, t_\ell.$$

5.2 Modulation

Humans have an almost unlimited variety of action maps once thinking is included as action, as Thoreau did when he wrote that Concord jail could confine his body but not his mind. In order to account for such variety it is convenient to think of action as generated at any one time by one among a *repertoire of behavior* represented by a countable set of *behavior maps*,

$$\mathcal{B} := \Big\{\beta_n : (m, s) \longrightarrow \beta_n(m, s), \; n \in N\Big\}.$$

Which map governs behavior at any given time depends on the agent state. Thus, let $\mathcal{R} := \{M_n, \, n \in N\}$ be a partition of a proper subset of $R \subset \mathcal{M} \times \mathcal{S}$. Then the action map (1) is defined by

$$\alpha(m, s) = \beta_n(m, s), \quad \text{if} \quad (m, s) \in M_n$$

or, equivalently,

$$a = \alpha(m, s) := \sum_{n \in N} \Delta\Big((m, s), M_n\Big) \tag{6}$$

19

where $\Delta((m,s), M) = 1$ if $(m,s) \in M$ and $= 0$ if $(m,s) \notin M$. Agent states act like a switch, directing action from one distinct mode to another. The term *to modulate* in music means to change keys; here it means *to change behavior* maps. That is, the action map modulates behavior.

That $\mathcal{R}$ is a partition of R implies that the agent has unambiguous motivation: a unique mode of behavior is selected for any $(m,s) \in R$.[14] However, for any $(m,s) \in \backslash R$ no mode of behavior is selected. That is, the agent can not exist.

5.3   General Properties of an Agent–Environment System

Using the above formalism as a metaphor for a person's behavior, it is reasonable to ascribe to it certain characteristics that have obvious empirical validity. These include:

A1. Agents begin. There is an initial time, t_0, and an initial behavior, β_1 such that $\beta_1(s(t_0), z(t)) \in A((s(t_0), z(t_0)) \neq \emptyset$.

A2. Behavior terminates. Given that an agent has begun, there is a time, $t_\ell > t_0$ such that $A(s(t_\ell, z(t''_\ell)) = \emptyset$.

A3. Behavior is locally unstable: it must switch modes. For any $i \in N$ and for any time, t, such that $((m(t), s(t)) \in M_i$ there exists a minimal time, $t' > t$, such that $(m(t'), s(t')) \notin M_i$, and either there exists a $j \in N$ such that $(m(t'), s(t')) \in M_j$, or $(m(t'), s(t')) \in \backslash R$.

A4. There exist recurrent behaviors. Given that $t_\ell - t_0$ is sufficiently long, there exists a subset $N^r \subset N$ (depending on $t_\ell - t_0$) such that if β_n, $n \in N^r$ prevails during an interval $[t_i, t_{i+1})$, then either there exists an interval $[t_j, t_{j+1})$ such that $(m(t), s(t)) \in M_n$ and $a(t) = \beta_n(m(t), s(t))$, $t \in$

---

[14]The assumption that $\mathcal{R}$ is a partition is not trivial. Psychologists have noted animal behavior in which internal states appear to simultaneously motivate different and conflicting actions. In such situations the animal exhibits seemingly meaningless or bizarre behavior. The human counterpart is suggested by the phrase 'being in a quandary.' If, however, in such a mental state the rule 'continue doing what you are doing,' or 'continue cogitating until a course of action is indicated,' is specified, then the required condition for well defined behavior can be restored.

$[t_j, t_{j+1})$ or behavior terminates. (This does not imply that behavior repeats at exactly even intervals or in any specific pattern.)

A5. There exist novel behaviors. Given long enough, a behavior that has never been pursued will be adopted. Let M_t be the set of indexes of behavior maps that have been used up to time t. At any time $t \geq t_0$ there exists a time $t' \geq t$ and a behavior map $\beta_j, j \notin M_t$ such that $a(t') = \beta_j(m(t'), s(t))$.

A consequence of the assumed properties is:

Behavior evolves. The history of action is described by a sequence of phases defined by the phase switching times $t_0, \ldots, \ldots, t_j, \ldots, t_\ell$. That is,

$$a(t) = \beta_j\Big(m(t), s(t)\Big), \ \ t \in [t_j, t_{j+1}), \ \ j = 1, 2, \ldots$$

with behavior modulating at every time $t_1, t_2, \ldots, t_j, \ldots, t_\ell$.

6 Abstract Adaptive Economies

This section formulates a general class of adaptive economizing or recursive programming models.[15] It then sketches the character of an abstract adaptive economy which takes a small step in the direction of a theory of a market economy evolving out–of–equilibrium.

6.1 L^* Programs

Consider an abstract parametric choice problem. Let x be a choice vector in a *plan space* $\mathcal{X}$. Let w be a datum in an *information* or *data space* $\mathcal{W}$. The (subjective) *feasibility correspondence* is $\Gamma : \mathcal{W} \to 2^{\mathcal{X}}$. Prioritization is represented lexicographically. Let $N := (1, \ldots, n)$. Let $(\varphi_i : \mathcal{X} \times \mathcal{W} \to \mathbb{R}, i \in N)$ be a family of preference functions arranged in a *priority order* given by the index i. Lexicographic choice is represented by the sequence of problems

$$\pi_i(w) := \max_{x \in \Psi_{i-1}(w)} \varphi_i(x, w), \ i \in N \tag{7}$$

---

[15]The following summarizes very briefly the basic ideas discussed in Day (forthcoming).

where $\Psi_0(w) := \Gamma(w)$. Lexicographic choices are constructed recursively by the sequence

$$\Psi_i(w) := \Psi_{i-1}(w) \cap \Big\{ x \mid \varphi_i(x,w) \geq \pi_i(w), \ i \in N. \tag{8}$$

Among the criteria of choice may be a priority based on a distance function requiring that the distance of a plan to a safe–enough set be minimized. It is assumed that underlying preference orderings are all representable by real valued functions. The generality of the notation does not imply anything about the dimensionality or complexity of the problems which may be as simple or as complex as is relevant.

The *lexicographic choice correspondence*, $\Psi_\ell : \mathcal{W} \to 2^{\mathcal{X}}$ by

$$\Psi_\ell(w) := \bigcap_{i \in N} \Psi_i(w), \ w \in \mathcal{W}.$$

Note that for $\ell = 1, \Psi_\ell(w) = \Gamma(w)$: *the highest priority is to find a feasible solution. In practice this may not be an easy problem. Indeed, it may be the most difficult problem in the sequence, the most costly one to solve, and the last one considered.* We adopt the hypothesis of satisficing in priority order using a family of satisficing functions $(\sigma_i : \mathcal{W} \to \mathbb{R}, \ i \in N)$ and a family of utility functions,

$$\varphi_i(x,w) := \min \Big[\mu_i(x,w), \sigma_i(w) \Big], \ x \in \mathcal{X}, \ w \in \mathcal{W}, \ i \in N, \tag{9}$$

where $\mu_1(x,w) \equiv \sigma_1(w) \equiv \sigma_1$ for all $w \in \mathcal{W}$. Given (9), the sequence (7) is an L^* *decision sequence* and Ψ_ℓ an L^* *choice correspondence*. A decision maker so described is an L^* *agent*, and a choice $x \in \Psi_\ell(w)$ is called an L^* decision.

As the L^* choice correspondence is set valued, define an L^* selection operator $\psi_\ell(w \to \mathcal{X})$ such that for all w, $\psi_\ell(w) \in \Psi_\ell(w)$. An important implication of this representation of choice based on prioritization of preferences is that ℓ depends on w. Thus, for each w there exists an $\ell \in N$ depending on w such that $\Psi_i(w) = \Psi_{\ell(w)}(w)$ for all $i > \ell(w)$. Call $\ell(w)$ the *determining criterion*. Correspondingly, the plan intended for period t can be represented by a map

$$x_t = \psi_{\ell(w_t)}(w_t).$$

6.2 A General Class of Recursive Progarmming Models: An L^* Agent in a Complex Environment

Imagine the L^* agent in a complex environment represented by the agent's internal and external environmental state, $s_t \in \mathcal{S}$ and $z_t \in \mathcal{Z}$, respectively, about which information is generated by a process

$$w_{t+1} = \delta(w_t, s_t, z_t) \tag{10}$$

which becomes the basis for a current plan or intended action $\mathcal{X}_{t+1}$ based on the L^* choice

$$x_{t+1} = \psi_{\ell(w_t)}(w_{t+1}). \tag{11}$$

In the meantime, internal and external states have been transformed by the maps

$$s_{t+1} = \sigma(a_t, s_t, z_t) \tag{12}$$

$$z_{t+1} = \omega(a_t, s_t, z_t) \tag{13}$$

so that plans may be adjusted correspondingly to arrive at action

$$a_{t+1} = \zeta(x_{t+1}, w_{t+1}, s_{t+1}, z_{t+1}). \tag{14}$$

In this particular and (necessarily) somewhat arbitrary discretization of the flow of action and states, the planning operator can be subsumed in the action transformer to get the composite action transformer

$$a_{t+1} = \alpha_{\ell(w_t)}(w_t, a_t, s_t, z_t) \tag{15}$$

in which intended plans become implicit in the generation of action. This shows that actions, information, and physical states evolve in the sense that they change over time, and in the sense that the structure of relationships evolve by switching from one preference ordering to another in the priority order, and that the structures of feasible regions and derived decision rules evolve as well. It is a form of modulation as described in §3.

Unknown to our decision maker—however sophisticated that agent may be—is the existence of a potentiality correspondence that determines the condition for which the action so generated can really occur independently of what the agent thinks about them.

We define a *region of potential action* that depends on the physical situation, apart from information about it,

$$A(s_t, z_t).$$

Action is potential if $A(s_t, z_t) \neq \emptyset$. The agent's *planning and control functions are practical* if and only if action is potential and

$$\alpha_{\ell(w_t)}(w_t, a_t, s_t, z_t) \in A(s_{t+1}, z_{t+1}). \tag{16}$$

6.3   An Abstract Adaptive Society

An abstract adaptive L^* society consists of a number of L^* agents interacting with each other and their common environment. Identify each agent by an index $k \in K := \{1, \ldots, \bar{k}\}$ and the information, plans, and action spaces associated with each by superscripts k. The number of agents' actions, plans information, and internal state spaces are described by the multi–vectors, $\mathbf{a} := (a^1, \ldots, a^{\bar{k}})$, $\mathbf{x} := (x^1, \ldots, k^{\bar{k}})$, $\mathbf{w} := (w^1, \ldots, w^{\bar{k}})$, and $\mathbf{s} := (s^1, \ldots, s^{\bar{k}})$, respectively. Assuming that an agent can generate information about other agents,

$$w_{t+1}^k = \delta^k(w_t^k, \mathbf{s}_t, z_t), \ \ k = 1, \ldots, \bar{k} \tag{10$'$}$$

$$x_t^k = \psi_{\ell(w_t^k)}, \ \ k = 1, \ldots, \bar{k} \tag{11$'$}$$

$$s_{t+1}^k = \sigma^k(\mathbf{a}_t, \mathbf{s}_t, z_t), \ \ k = 1, \ldots, \bar{k} \tag{12$'$}$$

Notice that individual agents' internal states are not independent but depend on other agents' internal states because of possible transactions among them.

The environmental transition is

$$z_{t+1} = \omega(\mathbf{a}_t, \mathbf{s}_t, z_t) \tag{13$'$}$$

and individual agent actions are now generated by the action maps

$$a_{t+1}^k = \alpha_{\ell(w_t^k)}^k(w_t^k, \mathbf{a}_t, \mathbf{s}_t, z_t), \ \ k = 1, \ldots, \bar{k}. \tag{15$'$}$$

The evolutionary structural change or regime switching property of the composite action transformer (15) carries over to the set of similar transformers (15$'$). This, however, is not an economy, not even an abstract one. That requires distinguishing between producers, consumers, market mediators, banks, a monetary authority, and a government sector.

6.4   Concluding Comments

As Henri Poincaré observed, "Trying to make science contain nature is like trying to make a part contain the whole." In other words, there can be no unique transformation from reality into models of it. The abstract model just presented, therefore, is not offered as *the* foundation for economic theory, but rather only as *a* foundation. More importantly it is offered as an example of a way to characterize salient properties of economic life as we know it and with which any scientific theory of economics should be consistent. Obviously, building on this foundation is not easy. It is much easier to stick to Pollyanna models that represent what *is* is the best it can be. That approach, however, does not survive in practical affairs of business and government longer than it takes to assert it. If one *thinks* as a Pollyanna, one must *act* according to ad hoc rules.

Within the intellectual domain of economic theory, we economists are typically far removed from the realities of business and government and focused on providing theorems rather than comprehending the complexity of the real world. We immunize ourselves from the considerations that help explain decisions in that arena including our own worldly actions as consumers and producers of intellectual goods. For how do *we* solve our complex problems? If you stop to think about it, *we* decomplexify *our* problems not like hommes d'affaires, but in ways appropriate to *our* tasks. Those ways include introducing simplifying, decomplexifying assumptions: regularity conditions (convexity, continuity, decomposability, linearity, etc.) for only in this way can we solve *our* problems. The practical expedients of businessmen and consumers are absolutely analogous. Our job is not how to economize *for* consumers, businessmen, and government agents. Rather, it is to *characterize* their behavior so that models of aggregate economic behavior can be constructed that offer explanatory power, at least some predictive capability, and that are close enough to what we know to be true at the micro level that their insights are convincing.

In spite of the great achievements of general equilibrium and temporary equilibrium theory, there is much to do.

References

[1] Bratman, Michael E. 1987. *Intention, Plans and Practical Reason.* Cambridge, MA: Harvard University Press.

[2] Chamberlin, E.H. "The Product as an Economic Variable." *Quarterly Journal of Economics* (1953): February.

[3] _____. 1957. *Towards a More General Theory of Value.* New York: Oxford University Press. Chapter 6.

[4] Cournot, A. 1963. *Research into the Mathematical Principles of the Theory of Wealth.* Homewood, IL: Richard D. Irwin, Inc. Originally published in 1838. Translated by Nathaniel T. Bacon and published in 1897.

[5] Day, R.H. and P. Kennedy. "Recursive Decision Systems: An Existence Analysis." *Econometrica* 38 (1970): 666–681.

[6] Day, R.H. "Rational Choice and Economic Behavior." *Theory and Decision* 1 (1971): 229–251.

[7] _____. 1975. "Rational Choice and Economic Behavior." R. Day and T. Groves, ed. *Adaptive Economic Models.* New York: Academic Press.

[8] _____. L'économie hors de l'équilibre." *Revue Économique* 46 (1995): 1461-1472.

[9] _____. 2004. *The Divergent Dynamics of Economic Growth: Studies in Adaptive Economizing, Technological Change and Economic Development.* New York: Cambridge University Press.

[10] _____. "On the Theoretical Foundation of Dynamic Economics: Remarks in Honor of Jean–Pierre Aubin." (forthcoming).

[11] Dewey, John. 19xx.

[12] Encarnación, J. "A Note on Lexicographical Preferences." *Econometrica* 32 (1964): 215–217.

[13] Georgescu–Roegen, N. "Choice, Expectations and Measurability." *Quarterly Journal of Economics* 68 (1954): 503–504.

[14] Grandmont, J.–M. 1988. "Introduction." J.M. Grandmont, ed. *Temporary Equilibrium: Selected Reading* (pp. xiii–xxv). New York: Academic Press.

[15] Herrnstein, R.J. and D. Prelec. "Melioration: A Theory of Distributed Choice." *Journal of Economic Perspective* 5 (1991): 137–156.

[16] Lancaster, K. 1971. *Consumer Demand: A New Approach.* New York: Columbia University Press.

[17] Leontief, W. "A Theoretical Note on Time–Preference, Production of Capital, Stagnation and Growth." *American Economic Review* 48 (1958): 105–111.

[18] Machiavelli, N. 1988. *The Prince.* Cambridge, UK: Cambridge University Press. Translated by Russell Price from the Bertelli edition of 1960. Originally written in 1513.

[19] Mannheim, K. 1936. *Ideology and Utopia.* New York: Harcourt Brace and Company.

[20] Marshall, A. 1920. *Principles of Economics.* 8th edition. New York: The Macmillan Company.

[21] Poincaré, Henri. 1952. *Science and Method.* "Mathematical Discovery." Chapter 11. Translated by Frances Maitland. New York: Dover Publications.

[22] Schumpeter, J.A. 1951. "Vilfredo Pareto." *Ten Great Economists: From Marx to Keynes.* New York: Oxford University Press.

[23] Simon, H. 1978. "Rationality as a Process and as a Product of Thought." *American Economic Review Papers and Proceedings* 68 (1978): 1–16.

[24] Walras, L. 1954. *Elements of Pure Economics or the Pure Theory of Social Wealth.* Homewood, IL: Richard D. Irwin, Inc. Translated by Willam Jaffe from the French edition definitive of 1926.