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Economic Decisions by Approved Principles: Rules of Thumb as Behavioral Guidelines

by Walter Buhr and Thomas Christiaans*

Abstract

We discuss the relevance of the concept of rational behavior in economic theory and suggest, on the basis of modern brain research results, to abstain from this notion and instead to apply behavioral rules of thumb in decision-making, especially if these rules can be derived from rational problem solutions determined by individual economic agents. We give an example for our point of view which refers to a contribution by *Baumol* and *Quandt* on the pricing behavior of a monopolistic firm and which also emphasizes the general importance of dynamic analysis in economics.

I. The concept of rational behavior in economic theory

In this paper we discuss the relevance of the concept of rational behavior in economic theory and suggest, on the basis of modern brain research results, to abstain from the assumption of rationality in solving economic problems and instead to apply behavioral rules of thumb in decision-making of individual economic agents.[1] From a normative point of view, it is reasonable to find rules that can be derived from rational problem solutions. With respect to positive economics, we argue that, in general, economic agents are not in a position to calculate rationally optimum solutions of their problems. Hence, it is important to investigate whether the implications of positive neoclassical economics are robust with respect to other behavioral assumptions. For our position we give an example which refers to a contribution by *Baumol* and *Quandt* (1964).

Substantial parts of economic theory are based on the assumption of rational behavior of human beings. The common understanding of the term *rationality* implies comprehensive information processing, far-reaching capabilities of calculation and sound reasoning that cannot be justified as the results of learning and adaptation (*Arrow*, 1987, p. 69). An economist's definition is more specific: Under the assumption of certainty, rationality of human behavior either means internal consistency of decision-making, for example, the realized requirement of transitivity, or reasoned pursuit of self-interest, in both cases the maximization of something (*Sen*, 1987, p. 69).

Sen (1987, pp. 68, 71) indicates that the interest in the concept of rational behavior stems from two motivations, on the one hand, from the normative question how one could behave rationally in a given situation, and, on the other hand, from the possible positive use of models of rational behavior in explaining and predicting actual behavior. The

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[1] We only consider decision rules in relation to human behavior and are aware that rules may also originate from experiences dealing with complicated problems, for example, the increase of labor productivity due to an improved division of labor or the interest of the private sector in a constant and permanent economic policy.

latter approach starts from the characterization of the implications of rational behavior, being aware that rationality is not a property of the individual alone, but derives its actual significance in the social context, in relation to other basic concepts of neoclassical theory such as equilibrium, competition, and completeness of markets, as *Arrow* (1987, pp. 71-73) convincingly demonstrates. Following this discussion, actual behavior is based on rational behavior. When we evaluate the unrealism of rational behavior, we should also consider the unrealism of any selected kind of irrational behavior. In general, there is no principle that prevents the formulation of an economic theory founded on assumptions other than that of rationality, although it is not an easy task to find alternatives for the standard hypothesis of rational behavior.

In this context it would go too far to investigate individual economic models whether, to what extent, and in which form they are devised on assumptions other than rationality. Therefore, at first, we should like to point out two mainstreams of economic thinking in the literature that show divergences from the hypothesis of rationality. The first group of models is related to different areas of applied economics and, due to its empirical and practical orientation, there is no major direct concern with rationality hypotheses. *Arrow* (1987, p. 70) gives practical theories of macroeconomics (in the field of Keynesian theory and monetarism) as examples (specifically cf. *Krusell* and *Smith*, 1996). Only by analysis one finds that rationality assumptions are partial and often supplemented by assumptions of a different nature.

The second group of models concentrates on bounded rationality, an approach developed by *Simon* (1957, 1979). The starting point is rational decision-making which is taken to be subjected to various restrictions (limited time span, uncertainty, market imperfections etc.), the result not being overall maximizing behavior, but a sequence of more or less independent and sometimes inconsistent decisions derived under partial information. A good and simple example is *Simon's* (1955) well-known *satisficing* hypothesis of behavior, meaning that economic agents perform limited searches over all possible decisions and then accept the first satisfactory alternative. For bounded rationality in economic models cf. *Conlisk* (1996).

Our aim now is to substantiate an existing third line of economic thinking on the basis of the theory of chemical and biological evolution as emerging from modern brain research. We propose that economic agents interested in optimal solutions follow rules of thumb as behavioral guidelines in decision-making, especially if it is possible to show that these rules can solidly be derived from or founded on models of rational behavior. As we shall argue, this suggestion takes into account the limited capabilities and specific working methods of the human brain. Moreover, given these limited capabilities of the brain, the positive use of models involving rules of thumb seems to be more reliable than using models of rational behavior. The following outline of the interaction of the essential parts of the vertebrate brain has been summarized from *von Ditfurth* (1976), except for other quotations indicated.

II. Some considerations on human behavior based on the results of brain research

Our brain must be understood as a chronologic arrangement in different layers which has developed in the process of chemical and biological evolution, in its course leading to psychic evolution (as general texts on the structure of the brain cf. *Popper* and *Eccles* (1977, 1987), *Schütz et al.* (1982), *Faller* (1995)). We are confronted with an anachronistic cooperation of the sections of the brain which are of totally different age; in their development they are millions of years apart. The hierarchical setup of the brain has been organized to improve the individual's chances of survival. Subsequently, our interest will be only in the psychic functions of the vertebrate brain and here again mainly in two parts of it. In the core of the brain we find (1) the diencephalon (including the center of vision) following and surrounding the brain stem. The diencephalon is superimposed by (2) the younger telencephalon or cerebrum which comprises seven-eightth of the mass of the vertebrate central nervous system.

The diencephalon includes the steering centers for inherent motion and the centers for processing information from the outside world. It generates natural instinctive behavior, emotions (feelings, sensations) and desires (instincts), being a storage place for experiences which are millions of years old. They influence our thinking and behavior without our own interference and generally unnoticed. The localization of specific behavior in the diencephalon is still unknown to a wide extent. However, there are certain indications as to the centers of anxiety states, the urge to locomotion, impetus reduction, the feeling of hunger, the rhythm of sleep and wakefullness.

Typical for the functioning of the diencephalon is the provision of a number of lines of conduct each of which appears to be totally natural, emerging from readily available behavior programs (cf. *Lorenz*, 1975). These programs (instincts, innate experiences) have optimally been adjusted to the environmental conditions in the course of evolution. They concern, for example, personal hygiene, reactions of defense, or provision of forage. Signals of the external world generate - beyond certain thresholds installed - releasing devices to stimulate the behavior programs in the diencephalon.

This part of the brain produces a representation of the world as a section of reality formed by the effectively perceived characteristics of the individual's environment. This representation of the outside world has not been derived by individual experiences, but by experiences of the human kind. There is a total correpondence between the inborne programs and reality of the external world as observed by the diencephalon (cf. also *Lorenz*, 1974).

The youngest and most progressive part of the brain, the telencephalon, renders possible conscious experiences, rational accomplishments, consciousness, capability of learning, and perception of the objective outer world.

The achievement of the individual's capability of learning which is the decisive step of evolution from the diencephalon to the telencephalon makes possible own experiences of the individual, the perception of the outside world in specific details, and the appearance of the objective world outside in the brain.

Up to the diencephalon the incoming information is concentrated and then, while it moves on to the telencephalon, is extremely dispersed to the different areas of the telencephalon. The areas of the cortex cerebri are uncommitted in the sense that they are not occupied by specific functions, programs, or instincts; they are freely available and give room for personal behavior. The forehead brain (frontal lobes) as most developed part of the telencephalon is the organ of human freedom, meaning that the telencephalon separates the individual from its environment.

The step-by-step development of the vertebrate brain leads to the consequence that all connections between the telencephalon and the external world must pass through the older parts of the brain, the brain stem and the diencephalon. The forehead brain and the rest of the cortex cerebri have no direct access to the outside world. The telencephalon is not a sovereign. Each information heading for the telencephalon must cross the diencephalon governed by its own archaic laws. This fact explains the irrationality, inconsistency and unreasonableness of human behavior (existence of wars, crimes, political narrowness in mind, religious fanatism etc.) which are basically due to the deep gap between the telencephalon and the diencephalon.

Both sections are cooperating parts of the same organ, the brain, considering their antagonistic nature. Thus the human being simultaneously lives in two worlds: on the one hand, it is capable of understanding and reasoning and, on the other hand, it exists in the transition of animal to man. Although the telencephalon has radically changed and improved the conditions and opportunities of man's existence, the diencephalon still plays a decisive role in shaping the thinking and the actions of human beings. To repeat, the diencephalon is incapable of learning and rational reasoning, bound to fixed problems and their solutions.

We are far away from objective rational experiences about this world.[2] We live in a subjective reality determined also by experiences not made by ourselves. Moreover, the capabilities of our senses are limited, our processing of information is characterized by particularities, and the development of the telencephalon in our brain is still in the state of immaturity.[3] In addition, the access to information is restricted so that information is an economic good carrying a positive price and thus leading to procurement costs.

As for empirical evidence, *Berk et al.* (1996) conduct an interesting test of rational decision theory. They consider the game show *The Price is Right* as a laboratory where the stakes are sufficiently high to ensure an economic incentive to play optimally (the contestants play for prizes worth as much as $60,000). The authors' result is that the players' strategies are transparently suboptimal. Interestingly, *Berk et al.* (1996) develop simple rules of thumb which explain the observed behavior better than rational decision theory.

The main result so far for our purposes is that we are well advised in economic analysis to give up our pretension to live in an objective, clearly concrete world and thus to drop the assumption of rationality in economic decision-making, a notion that is connected with the end of the information processing line in the telencephalon. (In this context we may question the justification of the term *bounded rationality*! However, this is a different research topic.) We suggest to give up the sole and strict references to the sphere of telencephalon and turn to the functions of diencephalon[4] which are structured in the form of programs. If we interpret a program as a set of rules, we understand the relevance of behavioral rules of thumb in economic decision-making. As a counterpoint to our argument we consider the fact that the now excessive urge to regulate too many aspects of modern private life is the result of growing human anxieties.

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[2] The claim to rationality is an overweening estimation of man, a form of dehumanization, that corresponds to the reality of human behavior, to the wicked shames of mankind in the sense of *Lorenz* (1980).

[3] On the interrelationships of information, organization, and incentives cf. *Will* (1998).

[4] On replacing the idealized, perfectly rational agents by *calibrated* agents who represent actual human behavior cf. *Arthur* (1993).

Any decision rule implies some type of justification, be it rational or irrational (cf. *Etzioni*, 1987, whose statements shall not be discussed here). However, decision rules are particularly convincing and valuable, if they can be derived from a rational problem solution. A good example for this third line of economics is the theory of investment evaluation, particularly cost-benefit analysis, and related areas of investment theory (cf., for example, *Day et al.*, 1974; *Ellison* and *Fudenberg*, 1993; *Rosenthal*, 1993). For the illustration of the wide applicability of our suggestion we shall discuss an example that draws on *Baumol* and *Quandt* (1964). This important contribution has widely been neglected as to its importance for neoclassical theory so that it deserves to be revived, especially in the present context; however, it must be corrected in an important aspect, as we shall demonstrate.

III. A stable rule of thumb for a monopolistic firm

Baumol and *Quandt* (1964) are the first to analyze the convergence of a *rule of thumb* – a *learning rule*, as they say – to an optimal supply price in a simple model of a monopolistic firm. They consider several types of pricing rules and give a rough classification of such rules.[5] In their Appendix A, they provide analytical proofs of stability for a (linear) discrete time model as well as a continuous time model, which, however, involves an error that is also present in *Gandolfo's* (1996, pp. 420–421) more general exposition of this model. We present the approach of *Baumol* and *Quandt* (1964) and *Gandolfo* (1996) and show how to reformulate the model in order to avoid this difficulty. We shall demonstrate that the chosen rule of thumb leads to the optimal solution after some time of – possibly cyclic – adjustment.

Although in reality a monopolist adjusts his price at discrete time intervals, we employ a continuous time approach. The following arguments can be given in favor of differential equations.[6]

1. There is no natural discrete unit of time. In this respect, choosing years; months or days is completely arbitrary. Therefore, in employing a discrete time model, it should always be checked whether its main implications depend on the chosen length of time intervals. If they are actually independent of period length, they should also be robust with respect to a change of the time span if it tends to zero, that is when we pass on from difference equations to differential equations.
2. Nonlinear discrete time models tend to show a very complex behavior. They may therefore imply chaos that arises only because of the chosen length of the period. Since a continuous time model can be interpreted as the limiting case of a model with very short periods, it should be observed, however, that a stable continuous model may be unstable in discrete time, if the adjustments do not occur in sufficiently small steps.
3. Even if difference equations are easy to use numerically, differential equations are analytically more tractable.

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[5] Other types are *markup rules*, *imitative rules*, and *pseudo maximizing rules*, cf. *Baumol* and *Quandt* (1964, p. 27).

[6] As for a more general outline of various arguments in favor of differential equations which comprises our arguments 1 and 3 cf. *Gandolfo* (1996, pp. 547–549). This book is also recommended as a general and comprehensible reference on differential (difference) equations and dynamic systems for economists.

With reference to the *Baumol* and *Quandt* model we also assume that profit π is given as a twice differentiable, strictly concave function of the price p satisfying

$$\pi = f(p), \qquad f''(p) < 0 \quad \forall p \geq 0,$$

which has its unique maximum at $\hat{p} > 0$ with $f'(\hat{p}) = 0$.[7] The monopolist does not know this profit function, except for some specific values of the function. Therefore, he uses the following simple rule of thumb: *Raise the price, if the profit change has been positive as a result of an antecedent increase in price, and lower the price, if the profit change has been negative. If the level of profits is stationary, do not change the price.* In other words, the price is changed in the same direction as in the previous period, if the change in profit has been positive, and in the opposite direction, if it has been negative.

The monopolist's application of this decision rule means that he is not obliged to solve explicitly his profit maximization problem in a rational way. He need not even have some notion of his specific market situation. In terms of brain research, the reference to the sphere of the telencephalon, to rational decision-making, may directly be neglected, being substituted by approaching the sphere of the diencephalon. This realm of the brain is governed by rules that are not subject to personal influences of the individual, but for mankind have emerged from the adjustment to the environment in the course of evolution, here to the monopoly situation of all individual suppliers who have ever produced under monopoly. The above given decision rule is particularly convincing and thus lasting, since it implies the convergence to the optimum solution of the monopolist's profit maximization problem, as will be shown.

A formal representation of the rule of thumb now to be discussed more thoroughly is

$$p_{t+1} - p_t = g\left(\frac{\pi_t - \pi_{t-1}}{p_t - p_{t-1}}\right) \tag{1}$$

where $g \in C^1(R)$ is a sign-preserving function fulfilling $g' > 0$, that is,

$$g \gtreqless 0 \iff \frac{\pi_t - \pi_{t-1}}{p_t - p_{t-1}} \gtreqless 0.$$

Using a quadratic profit function and a linear function $g(.) = k[(\pi_t - \pi_{t-1})/(p_t - p_{t-1})]$, $k > 0$, *Baumol* and *Quandt* (1964) show that the rule of thumb (1) implies a linear second order difference equation being characterized by the optimum price as a stable steady state, provided the adjustment speed k is sufficiently small.

In continuous time, their rule of thumb is approximated by[8]

$$\dot{p} = \begin{cases} g(\dot{\pi}/\dot{p}) & \text{if} \quad \dot{p} \neq 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

From the profit function, the authors derive $\dot{\pi} = f'(p)\dot{p}$; substituting this expression into the continuous rule of thumb yields

$$\dot{p} = g(f'(p)).$$

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[7] At $p = 0$, the terms $f'(p)$ and $f''(p)$ have to be interpreted as right-hand derivatives.

[8] *Baumol* and *Quandt* (1964, p. 43) use again a linear function g.

The properties of f and g imply that the function $h(p) := g(f'(p))$ satisfies

$$h(p) \gtreqless 0 \iff p \lesseqgtr \hat{p}, \quad \text{and } h'(p) = g'(f'(p))f''(p) < 0 \ \forall p \geq 0. \tag{3}$$

Baumol and *Quandt* (1964) conclude on the basis of relationship (3) that the profit maximizing price $\hat{p}$ is an asymptotically stable equilibrium of the differential equation $\dot{p} = h(p)$.

This result embodies a serious flaw, however. Equation (2) is inconsistent in itself, because it means that $\dot{p}$ can be positive and negative at the same time. For example, if $\dot{\pi} < 0$ and $\dot{p} > 0$ at some point in time, relationship (2) implies $\dot{p} < 0$. The reason for this obvious contradiction is a wrong inference regarding the continuous version of equation (1). Since this relationship is a second order difference equation, the corresponding differential equation must also be of the second order.[9]

A more reasonable continuous version of (1) that fairly well approximates the verbal rule of thumb is the following representation by a lagged differential equation:

$$\dot{p}(t+1) = \begin{cases} g(\dot{\pi}(t)/\dot{p}(t)), & \text{if } \dot{p}(t) \neq 0 \\ g(\ddot{\pi}(t)/\ddot{p}(t)), & \text{if } \dot{p}(t) = 0 \neq \ddot{p}(t) \\ 0, & \text{if } \dot{p}(t) = \ddot{p}(t) = 0 \end{cases} \tag{4}$$

Substituting $\dot{\pi}(t)$, respectively $\ddot{\pi} = f''(p)\dot{p}^2 + f'(p)\ddot{p} = f'(p)\ddot{p}$ in case of $\dot{p}(t) = 0$, into relationship (4) eliminates the case distinction and yields the only equation[10]

$$\dot{p}(t+1) = h(p(t)).$$

To get rid of the lag in this mixed difference-differential equation, subtract $\dot{p}(t)$ from both sides:

$$\dot{p}(t+1) - \dot{p}(t) = h(p(t)) - \dot{p}(t).$$

If the lag is reduced from one period to the fraction θ of this period, the change on the right-hand side should also be diminished to the fraction θ:

$$\dot{p}(t+\theta) - \dot{p}(t) = [h(p(t)) - \dot{p}(t)]\theta.$$

Dividing by θ and taking limits for $\theta \to 0$ yields the continuous adjustment process

$$\ddot{p} + \dot{p} = h(p). \tag{5}$$

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[9] One obtains a reasonable result despite the faulty approach, because $\dot{p}$ drops from the function g.

[10] Actually, the result of this substitution is

$$\dot{p}(t+1) = \begin{cases} h(p(t)), & \text{if not } \dot{p}(t) = \ddot{p}(t) = 0 \\ 0, & \text{if } \dot{p}(t) = \ddot{p}(t) = 0 \end{cases}$$

Clearly, the monopolist initially has to put the system into motion to get a reasonable rule of thumb, since if he starts with $\dot{p} = \ddot{p} = 0$, the system remains in this situation. If $\dot{p} \neq 0$ at the start, however, then it can be seen from the continuous version (5) that $\dot{p}(t) = \ddot{p}(t) = 0$ is possible only if $p(t) = \hat{p}$. Therefore, we do not have to bother about the second case.

This second order differential equation can be transformed into an equivalent system of two first order differential equations by introducing the new variable q defined by $q = \dot{p}$:

$$\begin{aligned} \dot{p} &= q, \\ \dot{q} &= h(p) - q. \end{aligned} \tag{6}$$

The unique equilibrium of this system is $(\hat{p}, 0)$.

It is important to notice that local stability results are only of a limited value in evaluating a rule of thumb, because such rules are only reliable, if they converge for initial values that are far off from an optimum. Moreover, for the problem at hand it does not make much sense, if the price approaches zero during the adjustment process. In order to meet these requirements, the following version of Lyapunov's second method – which allows for the explicit positivity condition $p > 0$ – is employed to prove the stability of the proposed rule of thumb.

Theorem. Let $f : X \to R^n$ *be a continuously differentiable function on the open state space* $X \subset R^n$. *Suppose that* $\hat{x}$ *is an equilibrium of the autonomous system* $\dot{x} = f(x)$.[11] *If there is a real-valued continuously differentiable function* $V : X \to R$, *a constant* $l > 0$, *and a nonempty and bounded region* $D \equiv \{x \in X : V(x) < l\}$ *such that*

$$\begin{aligned} &(a) \quad V(x) > 0 \ \forall x \neq \hat{x}, \ x \in D, \ V(\hat{x}) = 0, \\ &(b) \quad \dot{V}(x(t, x_0)) < 0 \ \forall x(t, x_0) \neq \hat{x}, \ x(t, x_0) \in D, \end{aligned}$$

then the equilibrium $\hat{x}$ *is asymptotically stable for all* $x_0 \in D$. *Every trajectory starting in D remains in D for all* $t \geq 0$.

Proof: Cf. *La Salle* and *Lefschetz* (1961), e. g. □

Proposition. The equilibrium $(\hat{p}, 0)$ *of system (6) is asymptotically stable. Its basin of attraction includes the region* $D = \{(p, q) \in R^2 : V(p, q) < l\}$, *where* $l = -\int_{\hat{p}}^{0} h(s)\, ds > 0$. *For all initial values in D, the price* $p(t)$ *is positive for all* $t \geq 0$.

Proof: The function

$$V(p, q) = \frac{1}{2}q^2 - \int_{\hat{p}}^{p} h(s)\, ds,$$

is a suitable Lyapunov function for $p > 0$. To prove this, observe that $V(p, q) > 0$ for all $(p, q) \neq (\hat{p}, 0)$ according to (3), and $V(\hat{p}, 0) = 0$. The derivative with respect to t is

$$\dot{V}(p, q) = q\dot{q} - h(p)\dot{p} = q[h(p) - q] - h(p)q = -q^2 < 0$$

for all $q \neq 0$. This proves $(\hat{p}, 0)$ is asymptotically stable. Now choose $l = -\int_{\hat{p}}^{0} h(s)\, ds > 0$ and define the region D of the theorem as $D \equiv \{(p, q) \in R^2 : V(p, q) < l\}$. Since

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[11] The solution of $\dot{x} = f(x)$ starting at $x(0) = x_0 \in X$ is denoted by $x(t, x_0)$.

conditions (a) and (b) of the theorem are satisfied for D, the proposition is proven, if it is shown that $p > 0$ in the case $(p,q) \in D$. From $V(p,q) < l$ we get

$$\begin{aligned} & \frac{1}{2}q^2 + \int_p^{\hat{p}} h(s)\,ds < \int_0^{\hat{p}} h(s)\,ds \\ \iff \quad & \frac{1}{2}q^2 + \int_p^{\hat{p}} h(s)\,ds - \int_0^{p} h(s)\,ds - \int_p^{\hat{p}} h(s)\,ds < 0 \\ \iff \quad & \int_0^{p} h(s)\,ds > \frac{1}{2}q^2 > 0, \end{aligned}$$

which requires $p > 0$ according to (3). Thus, $V < l$ implies $p > 0$; since V is decreasing along trajectories, $p(t) > 0$ for all $t \geq 0$. □

Figures 1 and 2 illustrate the argument by means of an example computed with *Mathematica*.[12] The region D is represented by the interior of the oval in each of the figures. The coordinate axes cut each other at the origin. The function $h(p)$ is affine and cuts the p-axis at the equilibrium value $\hat{p}$. The figures only differ with respect to the initial values of (p,q). It can be seen that the equilibrium is reached asymptotically regardless whether the initial values are inside or outside of D. In the latter case, however, p enters the negative region during the adjustment process.

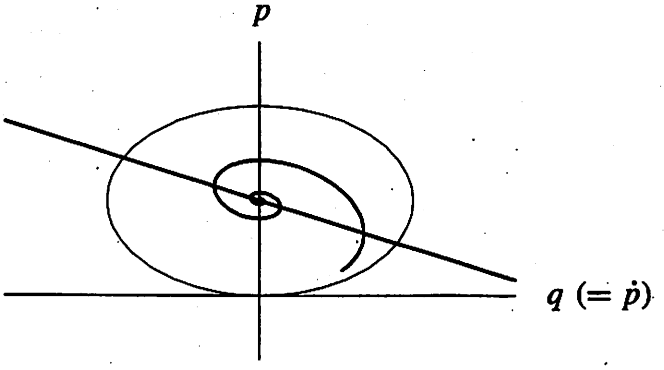

Figure 1: The phase plane of (6). The function $h(p)$ which is affine in this example cuts the p-axis at the unique equilibrium $(\hat{p}, 0)$. If $h'(\hat{p}) < -1/4$, it is a stable spiral, and otherwise a stable node. (The eigenvalues of the matrix A of the linearized version of system (6) at the point $(\hat{p}, 0)$ are $\lambda_{1,2} = -1/2 \pm \sqrt{h'(\hat{p}) + 1/4}$. Damped cyclic behavior near the equilibrium can therefore be excluded by choosing g' sufficiently small.) The figure shows a stable spiral. The region enclosed by the oval belongs to the basin of attraction and is defined by $V(p,q) < l$, where $l = -\int_{\hat{p}}^{0} h(s)\,ds > 0$. The trajectory with initial value inside the oval asymptotically approaches $(\hat{p}, 0)$ without leaving the region of positive p-values. (This figure assumes the demand function to be $x = 10 - p$ and the cost function to be $K(x) = x^2$, leading to the profit function $\pi = f(p) = 30p - 2p^2 - 100$. If we choose the function g as $g(f'(p)) = f'(p)$, we get $h(p) = g(f'(p)) = 30 - 4p$.)

It should also be noted that the model offers an explanation for a damped oscillatory movement of the price around its equilibrium value in a monopolistic market, although these oscillations can in principle be excluded by choosing g' sufficiently small (cf. the annotation to Figure 1).

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[12] *Mathematica* is a registered trademark of Wolfram Research, Inc.

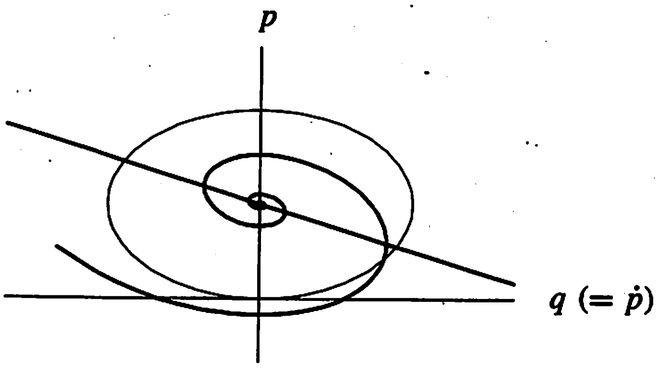

Figure 2: The phase plane of (6). The only difference in comparison with Figure 1 is that the initial value of the considered trajectory lies outside the region defined by $V(p,q) < l$. Although the initial value of p is positive and the equilibrium is reached asymptotically, p enters the negative region during the adjustment process.

The simple rule of thumb formally represented by (6) is asymptotically stable and does not violate the positivity condition for p, at least for initial values in $D = \{(p,q) \in R^2 \; : \; V(p,q) < \int_0^{\bar{p}} h(s) \; ds\}$. In other words, a monopolistic firm that uses such a rule of thumb has a good chance to end up in the true optimum without knowing its own profit function. This statement makes it much easier to trust in the results of the simple neoclassical model of monopoly because it is not necessary to assume that the monopolist knows his profit function.

IV. Concluding remarks

We have justified the application of behavioral rules of thumb on the grounds of brain research. Specifically, we have shown that a simple rule of thumb can be expected to lead to the true optimum of a monopolistic firm. Such results can raise the reliance on the implications of basic neoclassical models. Unfortunately, this model is only a first step considering its simple structure. Although it seems to be possible that similar results could be obtained for other static basic neoclassical market forms such as perfect and monopolistic competition or oligopoly, there is much less hope in formulating suitable rules of thumb for dynamic models. The reason is simple. On the one hand, in a static model we only have to look for some kind of method to find the roots of a (system of) equation(s). This approach resembles analogous mathematical procedures such as Newton's method, although the equations are known in the application of these methods while this is not the case for using a rule of thumb such as the one discussed here. On the other hand, the optimum in a dynamic model is not just a root of a system of equations but a solution of a system of differential equations that constitutes a boundary value problem, which is even difficult to approximate by a mathematical method, if the underlying model is completely known. Part of this difficulty stems from the fact that the optimal paths usually are, at best, saddle paths. The slightest error in determining the correct initial values will take the proposed solution away from the optimum solution. Clearly, these problems are reinforced if the true model is unknown.

As *Lettau* and *Uhlig* (1999) have shown, agents who are endowed with several (exogenously given) competing rules including the dynamic programming solution may fail to learn that the latter is indeed the optimum rule. This result depends on the so-called *good state bias* in a stochastic environment. If the suboptimal rule is only applicable in good states, whereas the dynamic programming solution is always a possible alternative, it may happen that agents falsely learn that the suboptimal rule is superior. While their assumption on the applicability of several competing rules seems questionable, the results of *Lettau* and *Uhlig* (1999) nevertheless indicate that, in an explicitly dynamic setting, it is quite possible that agents choose other solutions than the dynamic programming solution, even if it is one of the given alternatives. The argument of our paper goes a step further. In many applications it seems to be very dubious whether the dynamic programming solution is among the given alternatives at all. Therefore, the implications of such solutions for positive economics could only be relied on, if it would be possible to approximate the optimum solution by some kind of a simple rule.

The *Baumol* and *Quandt* (1964) model also points out another important methodological fact. Even if we are looking at basically static models, a dynamic analysis may lead to important additional insights. Since it is likely that a producer does not know the demand schedule he faces, for example, we believe that the use of static models is only really justified after the introduction of additional dynamic considerations. (The reader will observe the resemblance of this argument to *Samuelson's* celebrated correspondence principle.) Advocates of the neoclassical rationality postulate may object that a quasi-dynamic interpretation of such a basically static model involves conceptual problems, because a static objective function is used in a dynamic setting. This overall problem of repeating static decision problems becomes more significant in the case of dynamic interactions of several suppliers, as in the market form of oligopoly. In view of the results of brain research as well as of other evidence from the literature on bounded rationality, however, it is very doubtful whether economic agents are in a position to formulate a dynamic decision problem accurately at all.

A systematic analysis of neoclassical standard models aiming at the derivation of behavioral rules of thumb that require only a small amount of information is still missing. In view of the importance of dynamic analysis also for analyzing static models of decision making and taking into account that there are many branches of economic theory that are inherently dynamic anyway, we conclude this paper with the observation that dynamic theory should be of central concern in economics now and in the future.

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