BEHAVIORAL ECONOMICS AND BEHAVIORAL MOMENTUM

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Some relations between elasticity of demand and the conditions of reinforcement are reanalyzed in terms of resistance to change, in ways suggested by the metaphor of behavioral momentum; some relations between resistance to change and the conditions of reinforcement are reanalyzed in terms of elasticity of demand, in ways suggested by behavioral economics. In addition, some data on labor supply in relation to variable-ratio schedules and alternative reinforcement are reanalyzed in terms of resistance to change and compared with steady-state resistance data for performance on multiple and concurrent interval schedules. The results of these studies can be summarized by two functions based on the behavioral momentum approach, relating relative behavioral mass to relative reinforcement per response or per unit time. The former is a relation between relative unit price and relative behavioral mass, suggesting the possibility of convergent measurement of a theoretical construct common to both approaches. However, the momentum and economic approaches differ fundamentally on whether it is preferable to construe discriminated operant behavior as selected and strengthened by its consequences or as part of a behavior–consequence bundle that maximizes utility.

Key words: resistance to change, demand elasticity, labor supply, ratio schedules, interval schedules, lever press, key peck, rats, pigeons

Over the past 20 years, the conceptual structure of microeconomics has been brought to bear on operant performances maintained by schedules of reinforcement in monkeys, pigeons, and rats. Procedural constraints have been characterized as budget lines, data have been described in terms of demand curves, and interpretations have invoked indifference contours, marginal utility, optimality, and substitutability (e.g., Hursh, 1980; Rachlin, Battalio, Kagel, & Green, 1981). This approach is compelling for at least two reasons. First, there is a lot in common between the situation of the monkey, pigeon, or rat responding for a restricted resource such as food or water and the situation of the human consumer spending a restricted budget on desired commodities (e.g., Allison, 1981). Second, the behavioral economic approach can reveal consistent order across a wide range of experimental variables (e.g., DeGrandpre, Bickel, Hughes, Layng, & Badger, 1993).

The behavioral economic analysis of demand for a commodity emphasizes the relation between consumption and price and the dependence of that relation on the availability of substitutes. When the commodity in

question is one of the classic reinforcers such as food or water, and no alternatives are available, the usual finding is inelastic demand: When response requirements are increased, responding increases so as to defend normal consumption. However, demand becomes more elastic—more sensitive to increased response requirements—when the magnitude of the reinforcer is reduced or when a substitutable alternative is available. Thus, consumption is more or less elastic depending on the context in which it is examined.

There is a direct parallel in the study of resistance to change, which emphasizes the effects on responding (rather than consumption) of variables that generally decrease response rate. In multiple schedules of reinforcement, where distinctive stimuli signal different reinforcer rates or amounts, response rate is more resistant to change in the component with relatively larger or more frequent reinforcers (see Nevin, 1979, 1992b, for review). Also, for a given reinforcer rate, resistance to change depends inversely on the reinforcer rate in the alternated component (Nevin, 1992a). I have related these findings to the strengthening effects of the stimulus–reinforcer contingencies, but they could equally well be expressed in economic terms: Responding maintained by large or frequent reinforcers is less elastic than that maintained by small or infrequent reinforcers, and its elasticity depends on the availability of sub-

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stitutes within the experimental setting. This article will explore the parallel between economic and momentum analyses more fully. However, these approaches entail radically different conceptions of behavior and its consequences that should be made explicit at the outset.

The behavioral momentum approach affirms the traditional Skinnerian position that consequences select and strengthen the operant class on which they are contingent. This position was clearly articulated by Morse (1966), who described performance on intermittent schedules as the joint outcome of the shaping and strengthening effects of reinforcement. Shaping, in Morse's account, referred to differential reinforcement of inter-response times or patterns of responding, and strengthening referred to the general rate-enhancing effects of reinforcement. Subsequent research and theory (e.g., Baum, 1973; Vaughan & Miller, 1984) have examined the relative importance of local and global contingencies in the determination of response rate. However, the issues in that debate are irrelevant to the conception of strengthening advanced here, which is that "response strength" should be identified not with maintained response rate but with the resistance of response rate to change. However the behavior-reinforcement contingencies may be characterized, environmental stimuli set the occasion for them to operate, and the resulting correlation between reinforcers and environmental stimuli strengthens behavior emitted in their presence. The quantification of resistance to change as a measure of strength that is independent of baseline response rate, and its orderly dependence on stimulus-reinforcer contingencies, have added some empirical substance to the notion of strengthening by reinforcement (see Nevin, 1974b, 1979, 1992b, for review).

The behavioral economic view of interactions between the organism and its environment suggests that there is no fundamental difference between behavior and its consequences: Both instrumental and consummatory behavior are treated as commodities on indifference-curve axes, and the level of responding is a by-product of the instrumental-consummatory bundle that maximizes overall utility under contingency constraint (e.g., Rachlin et al., 1981). Related accounts that

do not invoke the notion of optimality also stress the reallocation of instrumental and consummatory behavior on the basis of contingencies that force deviations from their free or noncontingent baseline levels (e.g., Timberlake & Allison, 1974) or regulatory processes that minimize deviations from biologically given set points under the challenge of contingencies (e.g., Hanson & Timberlake, 1983). In all these accounts, both instrumental and consummatory behavior are reallocated in relation to the contingencies connecting them, and consummatory behavior has no special status. Consequently, the distinction between operants and their consequences becomes blurred, and the very notion that reinforcement selects and strengthens behavior becomes superfluous.

Allison (1981) has suggested that the notion of strengthening by reinforcement is not only superfluous but may even be misguided. For example, he reports that although a contingency that requires lever holding in order to gain access to drinking may increase lever holding relative to a baseline condition with both lever and water freely available, a return to baseline leads to immediate drinking rather than lever holding and reduces overall session average lever holding to near-precontingency levels. On its face, this result (which makes sense from an economic perspective) seems to be incompatible with the notion that reinforcement of lever holding by drinking has strengthened lever holding.

From a behavioral momentum perspective, Allison's (1981) example is a particularly challenging resistance test, and it is not surprising that lever holding is sharply reduced. However, if the amount of lever holding on return to baseline is an increasing function of rate or amount of access to water or length of training with the contingency in effect, the notion of strengthening might be tenable. In a similar experiment, Lentz and Cohen (1980) trained pigeons to peck a key for food on a variable-interval (VI) schedule and placed a dish of free food in the chamber during Sessions 6, 12, 24, 48, and 96. Typically, the birds ate for about 9 min and then pecked the key at low and variable rates. However, the average rate of key pecking in test sessions increased from about 3% of baseline in the first test to about 20% of baseline in the final tests. This result is entirely con-

Fig. 1. The top panel presents the logarithm of the average number of pellets consumed by rats receiving either two, one, or 0.5 pellets per ratio completion in a closed economy as functions of the logarithm of the fixed ratio, which increased over successive days from 1 to 360 (adapted from Hursh et al., 1988). The middle panel shows that the functions in the top panel may be superimposed when the x axis is reexpressed as unit price (i.e., responses per pellet). The bottom panel displays the

sistent with a strengthening account. However, it is not likely that either example will be entirely convincing to those working within different frameworks, and I now turn to areas of convergence.

Elasticity of Demand and Resistance to Change

In view of the difference in fundamental conceptions of the reinforcement process, it is remarkable that the behavioral economic and behavioral momentum approaches can both accommodate a variety of data collected within the framework of either approach. To show this, I will begin by reviewing some data gathered specifically to evaluate demand in relation to unit price.

Hursh, Raslear, Shurtleff, Bauman, and Simmons (1988) trained eight groups of rats to press levers for food pellets in a closed economy with no other food source. For one group, each ratio completion produced two pellets; for a second group, one pellet was produced; and for a third group, one pellet was produced with a probability of .5 (the remaining five groups in the study are not considered here). Then, pellets were made available on fixed-ratio (FR) schedules that increased over 5 consecutive days. The top panel of Figure 1 shows that the number of pellets obtained per day decreased as the ratio increased. All three functions are monotonic decreasing and negatively accelerated on double-logarithmic axes, which are standard for the presentation of demand curves in economic analyses because the local slope indexes elasticity of demand. The slope depends on number of pellets per ratio completed, being shallowest with two pellets per ratio and steepest with 0.5 pellets per ratio over the full range of ratios explored, suggesting that elasticity of demand depends inversely on the number of pellets obtained per ratio completion. The functions resemble a host of other demand curves in the literature, with shallow slopes indicating inelasticity at

← same data as resistance-to-change functions by reexpressing the y axis as the logarithm of ratio completions relative to the FR 1 baseline, with the FR value scaled arithmetically.

low ratios shifting to steeper slopes indicating greater elasticity as the ratio increases.

In the middle panel of Figure 1, these data are replotted with respect to unit price (i.e., responses per pellet) on the x axis. Their tidy superimposition provides a strong argument for unit price as the determining variable (DeGrandpre et al., 1993). However, as presented in the top panel, the data may also be construed as showing that the resistance to change of consumption depends on the number of pellets provided per ratio completion. This alternative view is made explicit in the bottom panel, where the same data are reexpressed as ratio completions per day relative to the number completed on continuous reinforcement (CRF) and replotted on semilogarithmic axes. The functions are tolerably linear, and the slope differences are easier to see than in the top panel. This is the form in which I have presented a large number of results from experiments on resistance to change, and Hursh (1990)¹ has pointed out that demand curves and resistance-to-change plots may simply be different ways of looking at the same data. Just as the slopes of double-logarithmic functions measure elasticity, the slopes of semilogarithmic functions measure resistance to change: The shallower the function, the greater the resistance to change. It is evident that resistance to change of consumption is ordered according to the number of pellets obtained per ratio completion.

The resistance-to-change analysis in the bottom panel of Figure 1 treats the progressive increase in the FR requirement on the x axis as a disruptor of the FR 1 baseline, exactly as if it were a progressive increase in amount of food given in the home cage before a series of daily sessions (e.g., Nevin, Tota, Torquato, & Shull, 1990, Experiment 2; Nevin, 1992a). The appropriateness of this treatment is suggested by the work of Elmsmore (1971) and Nevin (1989).² Nevin trained pigeons in a discrete-trial procedure in which one keylight signaled food availabil-

ity on 100% of the trials and another signaled food availability on 25% of the trials. Trials ended after a single peck or after 5 s. When the birds were prefed in their home cages, the probability of responding decreased more on the 25% key than on the 100% key. In Elmsmore's discrete-trial procedure, one key color signaled food availability on 50% of the trials and another signaled food on 24% of the trials. Trials terminated after a specified ratio was completed or after 8 s. When the required ratio increased, the birds completed fewer of the 24% trials than the 50% trials. Thus, performance on the richer signaled schedule was more resistant to change in both studies, one using prefeeding and the other using increased ratio requirements as disruptors.

The Metaphor of Behavioral Momentum

Before attempting a similar analysis of research explicitly designed to evaluate behavioral momentum, I will review that approach by way of its metaphor.

In classical mechanics, momentum is the product of two independent aspects of a moving body: its velocity and its mass. I have argued that there are two analogous and independent aspects of behavior: its steady-state response rate and its resistance to change. In mechanics, one way to measure mass is to apply a known external force f to the body, measure its change in velocity Δv , and then calculate mass m as $m = f/\Delta v$. The behavioral analogue to mass may be calculated similarly as the value of a disruptive variable divided by the change in response rate. Unlike physics, however, behavior analysis has no common system of units to which all measurements can be reduced. Accordingly, behavioral mass must be treated as a relative, dimensionless measure. This can be done by applying an external variable x to two discriminated operants B_1 and B_2 (as in the examples above from Elmsmore, 1971, and Nevin, 1989) and calculating their relative mass: $m_1 = x_1/\Delta B_1$ and $m_2 = x_2/\Delta B_2$. Therefore,

$$m_1/m_2 = (x_1/\Delta B_1)/(x_2/\Delta B_2). \quad (1)$$

If a single value of x is applied equally to both operants, it cancels out, and the mass ratio is simply the reciprocal of the changes in response rate, where change is measured as log proportion of baseline response rate. The

¹ Hursh, S. R. (1990, May). *Elasticity of demand as a measure of resistance to change*. Paper presented at a symposium on Resistance to Change: Research and Theory at the meetings of the Association for Behavior Analysis, Nashville, TN.

² Nevin, J. A. (1989, March). *Extinction, satiation, and partial reinforcement*. Paper presented at the meetings of the Eastern Psychological Association, Boston, MA.

performance that is less disrupted, relative to baseline, is the more resistant to change, or has greater inertial mass in the momentum metaphor. This can be translated as “stronger” in a strengthening-by-reinforcement account (e.g., Nevin, 1974b) or “less elastic” in a behavioral economic account.

The estimation of relative behavioral mass can be improved by arranging several values of x , measuring changes in response rate in two discriminated operants, and then determining the slopes of the two functions relating the magnitudes of the changes to x . The logarithm of proportion of baseline has proven to be roughly linear against several different disruptors, so that slopes can be estimated satisfactorily by linear regression. The ratio of the masses is then estimated as the inverse of the ratio of the two slopes. This is the method that I used to integrate all of the published resistance-to-change data from my laboratory since 1965 (Nevin, 1992b).

Another approach to the measurement of mass ratios follows from noting that if values of x_1 and x_2 are found such that ΔB_1 and ΔB_2 are equal, Equation 1 becomes $m_1/m_2 = x_1/x_2$, or, in logarithms,

$$\log m_1 - \log m_2 = \log x_1 - \log x_2. \quad (2)$$

Equation 2 implies that if relative mass is invariant with respect to x —that is, $(\log m_1 - \log m_2)$ is a constant, as it should be if the mass ratio depends only on the conditions of reinforcement for the two operants—the functions relating ΔB_1 and ΔB_2 to $\log x$ must differ horizontally by a constant value of $\log x$. Thus, they can be superimposed for all values of ΔB by shifting one function along a log-scaled x axis, where the magnitude of the shift measures relative mass on a log interval scale. This approach was used by Nevin, Mandell, and Atak (1983) to demonstrate mass-ratio invariance and to quantify behavioral mass. I turn now to that study.

Resistance to Change and Elasticity of Demand

Nevin et al. (1983) trained 6 pigeons on two-component multiple VI VI schedules arranging 129, 42, or 10 food reinforcers per hour in all three possible pairwise combinations of different schedules. Sessions lasted 45 min, and the birds were maintained at 80% of their free-feeding weights by supple-

mental feeding in their home cages, thus defining an open economy. After 40 sessions of training with each schedule pair, resistance to change was tested by presenting response-independent food during 30-s timeout periods between components. The rate of timeout food was varied across successive tests separated by baseline redeterminations. The top panel of Figure 2 shows that response rates in the first session with timeout food, expressed as proportions of baseline and averaged across two determinations for all 6 birds, decreased monotonically with increasing timeout food rate on semilogarithmic coordinates (see Nevin et al., 1983, for individual-subject data). Slopes depended on the VI schedules, being shallowest with 129 reinforcers per hour and steepest with 10 reinforcers per hour, suggesting that behavioral mass is a positive function of reinforcer rate. The functions resemble a host of others that my colleagues and I have obtained in our research on resistance to change. As shown in the middle panel of Figure 2, these functions can be superimposed by shifts along a log-scaled x axis, where the magnitude of the shift measures log relative behavioral mass. The resulting superposition is similar to that of the demand curves of Figure 1 (middle panel), which is as it should be if relative resistance to change is unaffected by the value of the disruptor in both cases. In effect, it suggests that behavioral mass can play a data-organizing role similar to that of unit price. The relations between these variables will be discussed below.

In the bottom panel of Figure 2, I have replotted the data of the top panel as demand curves on double-logarithmic axes. Number of response-contingent reinforcers obtained on each of the three VI schedules is plotted for each of the five timeout food rates as a function of unit price, calculated post hoc as responses per obtained reinforcer, following Allison (1983), Hursh (1980), and Lea and Tarpy (1982). The lines connecting data points for equivalent timeout food rates for the three VI schedules are steeply negative in slope, indicating that consumption is highly elastic, a plausible result for an open economy with postsession feedings of substitutable food. Moreover, their slopes increase with increasing timeout food rates, as expected if demand becomes more elastic with increasing

Fig. 2. The top panel shows the logarithm of the proportion of baseline response rate as a function of the rate of food presentations during timeout between multiple-schedule components with pigeons as subjects. Data from Nevin et al. (1983) were averaged for each component schedule over conditions and subjects. The middle panel shows that these functions may be superimposed by transformation of the x axis according to estimates of relative

availability of substitutable food. Note that for each VI schedule, there is little change in the number of response-contingent reinforcers obtained as post hoc unit price increases. This rough constancy reflects the properties of the supply curve implied by VI schedules, on which obtained reinforcer rate is little affected by moderate decreases in response rate (Nevin & Baum, 1980).

Comparing the functions in the top panel of Figure 1 and the bottom panel of Figure 2 is more like comparing apples and alligators than apples and oranges. The subjects were rats versus pigeons, and the procedures employed closed versus open economies and single versus multiple schedules. Hursh et al. (1988) controlled price directly and allowed consumption to vary, whereas Nevin et al. (1983) constrained consumption by the VI schedules they arranged and allowed the pigeons to determine the price. Nevertheless, a common relation between demand and price can accommodate the data of both studies. Likewise, the bottom panel of Figure 1 and the top panel of Figure 2 suggest that a common positive relation between resistance to change and reinforcer amount or rate can account for the data of both studies, and the middle panels suggest that a unifying variable can be identified for each analysis. These commonalities suggest substantial overlap between economic and momentum analyses and raise the question of which is more general or conceptually parsimonious.

Some Issues of Interpretation

The commonality between resistance to change and reinforcer amount or rate in the two studies reviewed above can be challenged, because Hursh et al. (1988) measured resistance to change of consumption, whereas Nevin et al. (1983) measured resistance to change of responding. Although consumption generally decreased, Hursh et al. found that responding increased as the ratio requirement increased up to some large

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behavioral mass (see text). The bottom panel presents the data of Nevin et al. as demand curves, where the logarithm of obtained reinforcers per hour is related to the logarithm of responses emitted per reinforcer. The five functions are for the five rates of timeout food (including zero) shown in the top panel.

value, beyond which responding decreased for their one-pellet and 0.5-pellet groups, resulting in inverted U-shaped functions. Such functions are not comfortably accommodated by a momentum analysis. The problem, in part at least, is that when changes in instrumental behavior are examined in studies that vary price, the disruptor variable (FR value) is perfectly confounded with the behavior being disrupted (FR performance). Ideally, the disruptor—the external variable of the momentum metaphor—should be defined on a dimension that is operationally orthogonal to the behavior being disrupted. Increases in price are orthogonal to consumption, and that is why I examined the resistance of consumption to price changes in Figure 1.

Nevin et al. (1983) treated the presentation of free reinforcers during timeouts between components as orthogonal disruptors, but this may not always be proper. Consider a hypothetical experiment designed to compare the resistance to change of responding in two multiple-schedule components, in which one component arranges a schedule of sucrose reinforcement and the other arranges a different schedule of saccharine-flavored water reinforcement. If dry food is introduced during timeouts between components, the result might be a decrease in sucrose-maintained responding but an increase in saccharine-maintained responding, regardless of their respective schedules. An economic analysis would explain such a result in terms of substitutability and complementarity: Sucrose responding decreases because food substitutes at least partially for the caloric value of sucrose, whereas dry food and zero-calorie sweetened water may be complements, such that increasing the availability of one increases the demand for the other. In fact, an economic analysis identifies substitutes and complements by changes in demand for one commodity when the availability or price of another commodity is varied.

From the momentum perspective, in order to compare the resistance to change of two performances, it is necessary that the disruptor be applied equally to each. For example, one could evaluate the disruptive effects of VI schedules of punishment, conditioned suppression, extinction, or increased effort, all of which can be applied equally to operants maintained by different reinforcers, and

all of which have at least ordinally equivalent effects on performances maintained by different reinforcer rates or amounts (see Nevin, 1979, for review). Indeed, it is the generality of the relation between relative resistance and relative reinforcement across qualitatively different disruptors, as well as its constancy within disruptors, that makes the momentum approach worth pursuing. As in the hypothetical experiment above, behavioral economics may be able to specify important boundary conditions on the generality of momentum analyses.

Conversely, the momentum approach has generated results that may challenge the application of economic principles. For example, Nevin et al. (1990, Experiment 1) added variable-time (VT) food presentations to one component of a multiple VI 1-min VI 1-min schedule and observed lower baseline rates but greater resistance to prefeeding and to extinction in the VI + VT component. The results confirm other findings suggesting that the stimulus–reinforcer relation determines resistance to change or behavioral mass (e.g., Nevin 1992a; for review, see Nevin, 1992b). However, from an economic perspective, the availability of a substitutable response-independent alternative in the VI + VT component should make demand for response-dependent food more elastic and hence less resistant to change. It would be interesting to repeat Experiment 1 of Nevin et al. (1990) with increased price, defined as increased tandem ratio requirements in both components, as the disruptor. Perhaps the ordering of resistance to change in the two components would reverse, suggesting an important limitation on momentum analyses; but perhaps it would be the same as with prefeeding and extinction, suggesting that stimulus–reinforcer relations may alter the effects of economic variables.

Behavioral Momentum and Labor Supply

In the material above, I have concentrated on elasticity of demand because that seemed most clearly analogous to resistance to change. Economic analyses have also been applied to relations between reinforcement schedules and labor supply. Although the economic approach treats labor as a commodity, the emphasis on responding, as opposed to

Fig. 3. Average data for 4 pigeons trained on four different VR schedules. In Condition 2, the VR value was doubled relative to that in Condition 1 and free food was provided at a rate that exactly compensated for the effect of doubling the VR if the subjects continued to respond at the same rate. The resulting steady-state response rate in Condition 2 is expressed as the logarithm of the proportion of the baseline rate in Condition 1 (adapted from Green et al., 1982).

Fig. 4. Average data for 3 pigeons trained on multiple VI VI schedules on one key, with an FI 50-s schedule on a second key. The functions show how VI response rate changed within the 50-s interval after FI reinforcement (subdivided into 10-s intervals), expressed as the logarithm of the proportion of its rate in the first 10-s interval, for VI schedules differing in the number of reinforcers arranged per hour (adapted from Nevin, 1974a).

consumption, may make momentum analyses especially relevant to labor-supply research.

Green, Kagel, and Battalio (1982) trained pigeons to respond for food on variable-ratio (VR) schedules and then simultaneously doubled the VR requirement and introduced response-independent (free) food at a rate that exactly compensated for the reduction in response-contingent food that would have occurred if the birds continued to respond at a constant rate (in economics, this is known as income-compensated wage change or Slutsky substitution). Consideration of indifference functions and trade-offs between work and leisure (i.e., not responding) led the authors to predict that response rate would decrease even though total obtained reinforcers would also decrease as a result. Figure 3 shows that the average decreases, expressed as log proportion of baseline, depended on the value of the VR schedule maintaining the performance: The richer the schedule, in terms of reinforcers per response, the smaller the reduction in responding relative to baseline. Functionally, the result is similar to that of Hursh et al. (1988). Again, however, comparisons are suspect: Hursh et al. studied rats in a closed economy with a procedure that increased the ratio schedule rapidly in order to sweep out a complete demand curve within a

week and concentrated on consumption, whereas Green et al. studied pigeons in an open economy with a procedure that not only changed the ratio but also added compensating food, and concentrated on steady-state response rates.

Although momentum analyses have typically employed relatively brief, probe-like disruptors to evaluate resistance to change, Nevin (1974a) conducted a steady-state analysis of resistance to change that has some similarities to the work of Green et al. (1982). Pigeons were trained to peck a key for food on multiple VI VI schedules with 10-s components, with a concurrent fixed-interval (FI) 50-s schedule operating on a second key. Thus, there was an increase in the probability of reinforcement for alternative behavior (second-key pecking) as time elapsed within each 50-s cycle, and response rates on the multiple-schedule key decreased systematically within each 50-s cycle. The rate of decrease depended on the schedule: The less frequently the VI schedule arranged reinforcement on the multiple-schedule key, the steeper the slope. The results, shown in Figure 4, are similar to those of many probe-test determinations of resistance to change. This similarity suggests that the steady-state effects of alternative food on VI performance may be

Fig. 5. The left panel shows how the logarithm of relative behavioral mass depends on the logarithm of the relative number of reinforcers per response when performance is altered by increasing the FR (Hursh et al., 1988) or changing to VR plus free food (Green et al., 1982). The right panel shows how the logarithm of relative behavioral mass depends on the logarithm of the relative reinforcer rate when VI responding is disrupted by timeout food (Nevin et al., 1983) or by FI food reinforcement for a competing response (Nevin, 1974a). In both panels, the log mass and reinforcement values in the leanest condition are set equal to zero, and results for other conditions are expressed relative to that condition.

functionally similar to the steady-state effects of free food on VR performance, as reported by Green et al. (1982).

A Momentum-Based Summary

In Figure 5, I compare the relations between resistance to change and baseline reinforcement conditions for the four studies described above. For the data of Hursh et al. (1988), the slopes of the functions shown in the bottom panel of Figure 1 were estimated by least squares regression. For the data of Green et al. (1982), slopes were calculated directly from the relative reductions displayed in Figure 3. Then, for each data set, the slope estimated for each condition was expressed relative to that estimated for the leanest condition and inverted. These inverse slope ratios estimate behavioral mass for each condition relative to the leanest condition, and are shown in the left panel of Figure 5 as a function of relative pellets per ratio completed in the CRF baseline for Hursh et al. or relative reinforcers per response in the pre-substitution baseline for Green et al. Despite the differences between these studies, the resulting functions are quite similar.

The probe and steady-state resistance data for VI performances by pigeons, described above, were treated similarly. For both timeout food tests (Figure 2, top panel) and steady-state FI reinforcement of alternative

behavior (Figure 4), slopes were estimated by least squares regression. Then, for each data set, inverse slope ratios were calculated and plotted as a function of the ratio of the reinforcer rate in each schedule component relative to the leanest baseline schedule. The outcomes are shown in the right panel of Figure 5. Both functions are positively accelerated, and again they are quite similar to each other. They are also similar in form to those for ratio schedules in the left panel, suggesting substantial agreement across a wide variety of procedural parameters.

Although their forms are similar, the relative-mass functions for ratio schedules (left panel of Figure 5) are steeper overall than those for interval schedules (right panel of Figure 5). This difference may arise from the fact that when a resistance test is applied to performances maintained by ratio schedules, the resulting decrease in response rate is accompanied by a corresponding decrease in obtained reinforcer rate, perhaps leading to a further decrease in resistance to change, whereas a moderate decrease in response rate on interval schedules has little or no effect on obtained reinforcer rate.

Whatever the interpretation of the differences between functions, it is the similarities that are important. The fact that similar resistance-to-change functions can be derived from diverse procedures, some of which were

specifically designed to evaluate economic variables, attests to the generality and power of behavioral momentum analyses.

At this point, an explicit discussion of behavioral mass and unit price is in order. In connection with Figures 1 and 2 (middle panels), I suggested that behavioral mass may provide an organizing variable that is comparable to unit price, but in fact it is quite different. Unit price is defined as responses per reinforcer divided by reinforcer amount, so its value is independent of data. Behavioral mass, by contrast, is a higher order dependent variable that is derived from a data set and that requires, for its organizing value, a high degree of consistency in convergent measurement operations.

As shown in the left panel of Figure 5, relative behavioral mass is directly related to relative reinforcement per response and thus is inversely related to unit price of food. The relative utility of a behavior-food bundle, as evaluated by preference, is also related to reinforcement per response. Schwartz (1969) varied the FR schedules and reinforcer durations in the terminal links of concurrent chains schedules and found that initial-link preference roughly matched relative reinforcer time per response, which is equivalent to relative reciprocal unit price. Related research with concurrent chains schedules (e.g., Ten Eyck, 1970) has shown repeatedly that preference is directly related to relative reinforcement per unit time, consistent with the relative-mass functions in the right panel of Figure 5. Thus, it may be that behavioral mass and utility are names for related measures of a single underlying construct.

Conclusion

This paper has attempted to show that behavioral economics and behavioral momentum can be construed, to use an economic metaphor, as partial substitutes in their ability to reveal order in a substantial range of data. Despite their radically differing views of strengthening by reinforcement, they need not be competitors, and may even prove to be complements as converging approaches to the study of behavior.

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