JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1993, 60, 141–158 NUMBER 1 (JULY)

THE SUBSTITUTABILITY OF REINFORCERS

LEONARD GREEN AND DEBRA E. FREED

WASHINGTON UNIVERSITY

Substitutability is a construct borrowed from microeconomics that describes a continuum of possible interactions among the reinforcers in a given situation. Highly substitutable reinforcers, which occupy one end of the continuum, are readily traded for each other due to their functional similarity. Complementary reinforcers, at the other end of the continuum, tend to be consumed jointly in fairly rigid proportion, and therefore cannot be traded for one another except to achieve that proportion. At the center of the continuum are reinforcers that are independent with respect to each other; consumption of one has no influence on consumption of another. Psychological research and analyses in terms of substitutability employ standard operant conditioning paradigms in which humans and nonhumans choose between alternative reinforcers. The range of reinforcer interactions found in these studies is more readily accommodated and predicted when behavior-analytic models of choice consider issues of substitutability. New insights are gained into such areas as eating and drinking, electrical brain stimulation, temporal separation of choice alternatives, behavior therapy, drug use, and addictions. Moreover, the generalized matching law (Baum, 1974) gains greater explanatory power and comprehensiveness when measures of substitutability are included.

Key words: microeconomics, choice, substitutability of reinforcers, generalized matching law

The conceptualization of the nature of reinforcers continues to expand. Reinforcers, long viewed as fixed stimulus events that simply strengthen any response upon which they were contingent, came to be understood as occurring within a context. Originating with Premack's (1965) probability-differential response theory of reinforcement, the behavioral view of reinforcement broadened as response deprivation (Timberlake & Allison, 1974), conservation of behavior (Allison, Miller, & Wozny, 1979), and disequilibrium (Timberlake, 1980, 1984) theories were elaborated. Herrnstein's matching law (1961, 1970), which predicts that a given activity is influenced not only by the reinforcers contingent upon it but also by other reinforcers within the situation, made explicit the role that context plays in understanding reinforcement effects. The nature of reinforcers has been elaborated further by incorporating economic principles, specifically that of substitutability, into behavioral analyses in order to account for behavior when the outcomes (reinforcers) are not qualitatively identical (Rachlin, Battalio, Kagel, & Green, 1981; Rachlin, Green, Kagel, & Battalio, 1976). Indeed, it is reasonable to suggest that an adequate understanding of the interactions among reinforcers and their influence on behavior is not possible without a consideration of substitutability. Moreover, this understanding will undoubtedly have implications for areas such as choice, behavior therapy and behavior change, and the nature of addictions.

The goal of the present paper is to bring together the experimental psychological literature on substitutability and, in so doing, demonstrate the importance of including economic analyses, theory, and research in the psychological study of choice and the understanding of the nature of reinforcement.

We thank Howard Rachlin and William Timberlake for their useful comments and suggestions, Joel Myerson for his critique of an earlier version of this paper, and Heather Rehberg for making us aware of the literature on social support and risk behavior. Requests for reprints should be addressed to Leonard Green, Department of Psychology, Washington University, Campus Box 1125, St. Louis, Missouri 63130.

SUBSTITUTABILITY

Traditionally, knowledge of the properties of reinforcers was derived from examining the effects of a single reinforcer on a single activity (e.g., Berlyne, 1969; Hull, 1943; Logan, 1960). Herrnstein's (1961, 1970) formalization of the matching law was revolutionary because it made explicit the relativistic nature of reinforcers; that is, the effect of a reinforcer is dependent upon the context of other reinforcers in which it appears. The matching law states:

$$B_x/(B_x + B_y) = R_x/(R_x + R_y), \quad (1)$$

where B is some behavior, expressed in units of either responses or time, allocated to alternatives x and y, and R represents the reinforcers obtained from that behavior. Expressed as a ratio,

$$B_x/B_y = R_x/R_y. \quad (2)$$

Following from this relation is the notion that the effect of a given reinforcer is always context dependent; in other words, there are always other reinforcers in an animal's current environment from which to choose. By implication, then, all behavior can be construed as choice (Herrnstein, 1970). This can be derived from Equation 1 as follows:

$$B_x = [(B_x + B_y)R_x]/(R_x + R_y).$$

Replacing the quantity $(B_x + B_y)$ with k, we obtain

$$B_x = kR_x/(R_x + R_y). \quad (3)$$

Furthermore, the specific source of reinforcement, R_y, may be more generally understood as the "unknown, aggregate reinforcement f[rom] other alternatives" (Herrnstein, 1970, p. 255) and be represented as R_0; B_0, then, would represent all behavior allocated to those alternatives. This yields the following equation:

$$B_x = kR_x/(R_x + R_0), \quad (4)$$

where k now replaces the quantity $(B_x + B_0)$. Thus, the effects of a given reinforcer (R_x) on an activity (B_x) are necessarily modulated by context (R_0). Given that the effect of a reinforcer cannot be understood apart from its relation to other reinforcers, the study of reinforcer interactions is of paramount importance.

Behavior analysts have focused primarily on investigating the interactions of reinforcers that differ in their frequency, amount, delay, or probability. Rarely, however, have the interactions of reinforcers that differ along a qualitative dimension been examined. It is to this largely unexplored issue that consumer demand theory—specifically, the concept of substitutability—is particularly relevant. Psychologists' study of animals choosing between reinforcers has a direct analogue to economists' study of consumers choosing between commodities. Consequently, economic principles regarding the relationship between commodities should be equally germane to the interactions of reinforcers.

Substitutability is not a property of a single good, but rather is a characteristic of the relationship between commodities or reinforcers; thus, substitutability describes a continuum of possible interactions among reinforcers. Perfect substitutability and perfect complementarity define the ends of the continuum, with independence falling between the two. Rachlin (1989) discusses substitutability in terms of the extent to which two commodities are qualitatively similar. However, two commodities may share many qualitative similarities yet not be substitutable. For example, oranges and tennis balls are similar with regard to size, shape, weight, and firmness but quite dissimilar with respect to nutritional value. Are oranges and tennis balls substitutable or not? It depends. For the purposes of juggling, oranges and tennis balls are relatively good substitutes; however, when it comes to eating, tennis balls and oranges are highly nonsubstitutable. Consequently, a general definition of substitutability must take into account the function of the commodities in question. To this end, substitutable goods may be defined as those that serve similar purposes (Baumol, 1972). Some common examples of relatively substitutable goods include raincoats and umbrellas, Coke® and Pepsi®, and zippers and buttons.

But what of goods that do not serve similar purposes? Goods that are not functionally similar may be either complementary or independent commodities. When two commodities are used jointly, these goods can be considered complementary (Baumol, 1972). Complements might include commodities such as bagels and cream cheese, kites and string, paint and canvases. However, some pairs of commodities are neither substitutes nor complements, but rather are independent goods. Returning to our previous example, oranges and tennis balls are usually independent commodities (except when it comes to juggling). Of course, a good need not serve only one function. Thus, substitutes and complements are not fixed categories or points on a continuum.

Substitutability and complementarity can be judged by the degree to which consumption of one commodity changes as the value of an alternative commodity is altered. (See Samuelson, 1974, for a discussion of six tests for substitutability and complementarity that historically have been attempted, none of which need be incompatible with the informal definition given here.) For both substitutable and complementary goods, altering the price of one commodity in a pair produces specifiable changes in consumption of both commodities: If the price of one commodity were to decrease, its consumption would increase while that of its substitute would decrease, whereas consumption of its complement would increase. For independent goods, altering the price of one commodity has little or no effect on consumption of the other (Schwartz, 1989).

Substitutability may be understood in terms of Figure 1. The solid line is a budget constraint determined by the price of Commodities X and Y and total income available. The filled circle on the solid line represents one possible "package" of Commodities X and Y chosen. The dashed line is a new budget constraint imposed by decreasing the price of Commodity Y and increasing the price of Commodity X. In economic terms, the dashed line represents an income-compensated price change from the solid line. Under an income-compensated price change, total income is adjusted to keep real income constant so that the identical package of commodities can still be obtained under the new set of prices as was obtained under the previous budget constraint. The same package can be chosen under the new budget because this line passes through the filled circle—the previously chosen combination of X and Y. Consequently, any change in consumption of the two commodities must be due to the difference in the slopes of the two budget constraint lines. If the price of one commodity were decreased without adjusting total income (i.e., a noncompensated price change), then the amount of real income available would increase. A change in the consumption of the commodities, then, might reflect an increase in real income, a substitution effect, or both. However, when income is adjusted to keep real income constant as prices are changed, the original package of commodities may still be purchased at the new prices. Therefore, any change in consumption from that original package is indicative of a substitution effect rather than an income effect. (See Green, Kagel, & Battalio, 1982, for further explanation.) The degree of substitutability between the two commodities shown in Figure 1 is represented by the degree to which consumption shifts in the direction of the other symbols, with the triangle, square, and cross representing increasing degrees of substitution from Commodity X into the made-cheaper (relatively) Commodity Y. (For a fuller description, involving, as it must, the details of indifference contours, see Rachlin, 1989.)

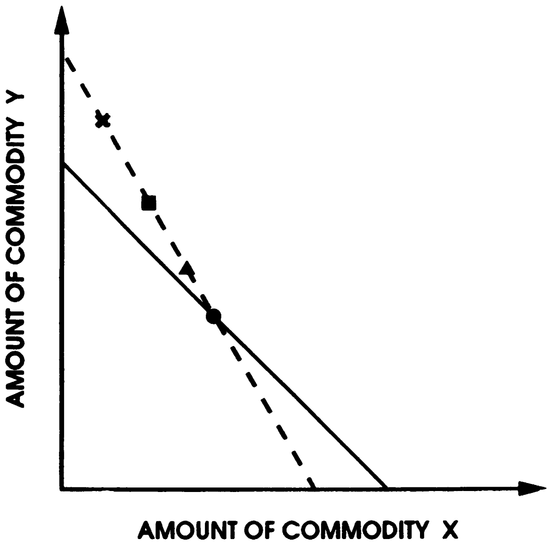

Fig. 1. An economy in which Commodities X and Y may be purchased. The solid line represents a budget constraint as determined by the prices of the two commodities, X and Y, and total income. The filled circle represents one possible "package" of X and Y purchased. The dashed line shows another budget constraint determined by decreasing the price of Commodity Y and increasing the price of Commodity X. This budget constraint, referred to as an income-compensated price change (see text for a more detailed explanation), is selected so that it passes through the filled circle, thus allowing the subject to obtain amounts of both commodities identical to those obtained under the original budget constraint. The triangle, square, and cross on the dashed line represent successively greater degrees of substitutability of Commodity Y for Commodity X.

Consider the following hypothetical example. If the price of Coke were to remain constant while the price of Pepsi were to decrease, we would expect a large decrease in consumption of Coke, assuming that Coke and Pepsi were highly substitutable. If, in fact, Coke and Pepsi were perfect substitutes, then for every amount, X, of Coke given up, consumption of Pepsi would increase by amount pX (Allison, 1989).[1] Conversely, decreasing

[1] The constant p allows that the exchange between perfect substitutes may not necessarily be in the ratio of 1:1. For example, if both Coke and Pepsi came in 16-oz bottles, then for every bottle of Coke given up, consumption of Pepsi would increase by one bottle and the exchange would be in the ratio of 1:1. However, if Coke came only in 16-oz bottles and Pepsi came only in 12-oz bottles, then for every bottle of Coke given up, consumption of Pepsi would increase by 1.33 bottles—an exchange ratio of 1:1.33.

the price of Pepsi might produce an increase in consumption of Doritos® even though the price of Doritos had not changed, because soft drinks and snack foods tend to be consumed jointly. Finally, decreasing the price of Pepsi would probably have little effect on the consumption of automobiles; these two commodities are independent.

One reason that substitutability has received little attention in the operant conditioning literature may be the fact that psychological studies of choice have, almost exclusively, examined the effects of variables that control choice between qualitatively similar (usually identical), and therefore substitutable, reinforcers. A typical choice experiment involves hungry pigeons choosing between identical food reinforcers that differ in their frequency, duration, delay, or probability. Hursh and Bauman (1987) have suggested that this is akin to studying consumer behavior in a store that sells only one product.

Economists, on the other hand, have for the most part studied the interactions among nonsubstitutable commodities. However, their analyses have taken place in the absence of empirical tests with individual animals (Hursh & Bauman, 1987). Psychologists recently have begun to fill this gap predominantly, although not exclusively, by studying nonhuman subjects, and in so doing have found cause to revise their theories of choice and reinforcement.

The value of integrating economic with psychological analyses that incorporate substitutability is evident from Hursh's (1991) consideration of the use of methadone in the treatment of heroin abuse. Methadone treatment has been a common form of therapy for heroin addicts. However, the extent to which methadone will effectively decrease heroin use is dependent on how substitutable methadone is for heroin. Methadone is less than perfectly substitutable for heroin for a variety of reasons. One of these is that methadone is administered in doses designed specifically not to induce the same degree of euphoria as heroin. Moreover, methadone, because it is dispensed at regular intervals in a clinical setting rather than "on demand," is not as readily available as heroin. (And, as we will discuss in a later section, temporal separation between two otherwise identical reinforcers reduces the degree to which they are substitutable.) The lack of complements may be another variable that strongly attenuates the degree of substitutability between methadone and heroin. Heroin is frequently administered as part of an elaborate social ritual that may function as a complement to drug taking. "To the extent that the substitute, methadone, must be consumed in a clinical, nonsocial environment, its value will be diminished as an adequate substitute for heroin because it is not accompanied by important complementary social reinforcers" (Hursh, 1991, p. 384).

PSYCHOLOGICAL STUDIES OF SUBSTITUTABILITY

In one early examination of substitutability (Kagel et al., 1975; Rachlin et al., 1976), rats' responding for two different reinforcers (either root beer and Tom Collins mix or food and water) was studied under concurrent fixed-ratio (*conc* FR) schedules of reinforcement. Each of the two reinforcers was associated with a unique response lever and FR requirement. However, unlike the short-duration sessions of more typical operant experiments, the rats lived in the experimental chamber and were limited to a fixed number of lever presses in a given 24-hr period. This paradigm has obvious parallels to an economy: The pairs of reinforcers constitute different commodities, the FR requirements determine the price of each good, and the total number of level presses allotted specify the rat's income. Thus, it is possible to study substitution effects between different commodities with rats as consumers.

Each set of prices and income constituted an experimental condition. The Tom Collins/root beer rats initially had an income of 300 lever presses, and the price of both the Tom Collins and root beer was an FR 1 schedule delivering 0.05 mL of fluid. As can be seen in Figure 2 (top and middle graphs, Budget Line 1), both rats strongly preferred root beer to Tom Collins. In the next condition, the price of Tom Collins was halved (by doubling the amount delivered each time) and the price of root beer was doubled while the income of each rat was adjusted so that it could still obtain the same combination of root beer and Tom Collins as it had in the first condition. This income-compensated price change is represented by Budget Line 2 in the top and middle graphs. In this second condition, the rats con-

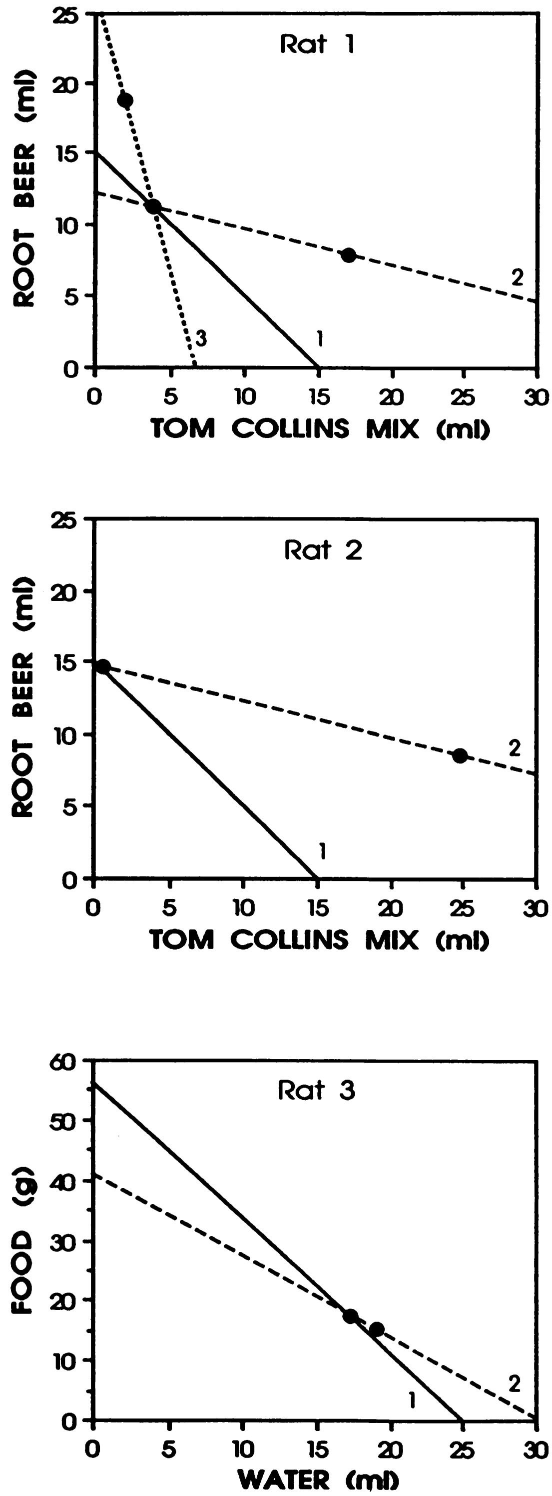

Fig. 2. Individual rats' data under different budget constraints in which the commodities were root beer and Tom Collins mix or food and water. The top and middle graphs present the combinations of root beer and Tom Collins chosen by Rats 1 and 2, respectively; the bottom graph shows the combinations of food and water chosen by Rat 3. Baseline budget conditions are represented by solid lines (Line 1), and income-compensated price changes are represented by the dashed lines. (Adapted from Kagel et al., 1975, and Rachlin et al., 1976.)

sumed much more of the now-cheaper Tom Collins mix than the more expensive root beer. When prices and income were returned to their initial baseline values, consumption likewise returned to or near baseline levels (not shown in Figure 2). When for Rat 1 the price of root beer was halved, the price of Tom Collins doubled, and total income again adjusted so that baseline amounts could still be obtained (Budget Line 3 in the top graph), consumption of the cheaper root beer increased while consumption of the more expensive Collins decreased, with the rat now consuming 10 times as much root beer as Tom Collins. As Rachlin et al. (1976) suspected, root beer and Tom Collins proved to be highly substitutable commodities: When the price of one liquid was increased, consumption of that liquid decreased and consumption of the alternative drink increased. It is important to note that these substitution effects occurred independently of preference—when the price of root beer and Tom Collins was equal, root beer was the highly preferred commodity, yet that preference was eliminated entirely when the price of root beer was increased.

The same basic procedure was also used to examine the degree of substitutability between food and water. At baseline (Figure 2, bottom graph, Budget Line 1), Rat 3 had an income of 2,500 presses, the price of five food pellets was 10 presses, and the price of 0.10 mL of water was 10 presses. In the next condition, the price of food was increased 67% (10 presses now delivered three food pellets), while income was also increased so as to allow baseline amounts of food and water to be purchased (Budget Line 2). Although a slight shift in consumption in the direction of the relatively cheaper water did occur, this shift was considerably less dramatic than that in the Tom Collins/root beer case, providing support that food and water are highly nonsubstitutable and, in fact, relatively complementary goods.

Hursh (1978) provided further evidence that

Table 1

Responses and reinforcers per hour for the constant food and water as the frequency of the alternative food was varied. Data are from Hursh's (1978) Experiment 1 (closed economy) and Experiment 2 (open economy).

		Closed economy (Experiment 1)				Open economy (Experiment 2)			
		Responses/hr		Reinforcers/hr		Responses/hr		Reinforcers/hr	
Subject	Alternative food schedule (VI)	Constant food	Water	Constant food	Water	Constant food	Water	Constant food	Water
SM2	—	4,668	275	58	44	—	—	—	—
	480	3,808	612	58	47	3,196	543	57	46
	240	3,449	610	58	46	3,428	716	56	47
	120	1,518	1,968	56	52	2,576	690	57	43
	60	734	2,652	49	55	2,088	1,085	56	51
	30	288	3,888	40	58	2,209	697	59	47
SM3	—	1,891	183	32	34	—	—	—	—
	480	1,578	403	60	52	2,241	613	59	53
	240	1,171	730	57	54	2,586	552	55	45
	120	444	1,173	50	55	2,113	168	57	33
	60	264	1,046	36	54	1,983	293	56	40
	30	241	2,095	25	61	1,112	381	57	51

food and water are complements in a pair of experiments with rhesus monkeys. Identical food pellets were available for responding on two levers; water was available for responding on a third lever. The water and one food source (the constant food) were always available on variable-interval (VI) 60-s schedules, while the rate of access to the alternative food source varied from VI 30 s to VI 480 s across conditions. In one condition, no alternative food source was available. If the alternative food is substitutable for the constant food, then responding for and consumption of the constant food should decrease as the alternative food increases in frequency. If the alternative food is a complement for water, then responding for and consumption of the water are expected to increase with increased availability of the alternative food.

The first experiment studied the monkeys under a closed economy. In a closed economy, the subjects earn their total daily consumption of the reinforcers during the experimental session. No postsession feeding is given (Hursh, 1980). Hursh found that the presence of the alternative food resulted in decreased responding for the constant food but increased responding for the water: As shown in Table 1, when the alternative food was introduced on a VI 480-s schedule, SM2 decreased responding for the constant food by 18% and increased responding for water by 123%. SM3 demonstrated a similar pattern, decreasing its responding by 17% for the constant food and increasing its responding by 120% for water when the alternative food was added on a VI 480-s schedule.

Furthermore, changes in the frequency with which the alternative food was obtained produced direct changes in responding for and consumption of the water, but produced inverse changes in responding for and consumption of the constant food. Thus, when the alternative food was made more readily available, the monkeys reduced responding for and consumption of the constant food and substituted into the now-cheaper alternative, but increased responding for and consumption of the water, even though its availability had not changed. This result is clearly demonstrated in the comparison of response rates when the alternative food was changed from a VI 480-s schedule to a VI 30-s schedule: SM2 reduced its responding for the constant food by 92% and increased its responding for water by 535%; similarly, SM3 reduced its responding for the constant food by 85% and increased its responding for water by 420%. Similar, though less dramatic, patterns of change occurred in consumption rates (reinforcers per hour). Increasing the rate of the alternative food from VI 480 s to VI 30 s reduced consumption of the constant food by 31% for SM2 and by 58% for SM3; consumption of water increased by 23% and 17% respectively.

In Hursh's (1978) second experiment, the same monkeys were exposed to the conditions of an open economy under which consumption of food and water was held constant across sessions. That is, total daily intake of food and water was regulated by consumption both during experimental sessions and by postsession feedings. In short, deprivation was constant from session to session (Hursh, 1980). Therefore, unlike the closed economy, daily intake of food and water was not determined exclusively by the monkeys' interactions with the experimental contingencies. In all other respects, however, the procedures replicated those of the first experiment.

This experiment demonstrated that substitutes and complements are differentially affected by economy type. In this open economy, responding for the constant food decreased much less sharply compared to that in the closed economy as the frequency of the alternative food increased. As shown in Table 1, as the frequency of the alternative food was increased from VI 480 s to VI 30 s, SM2 decreased responding for the constant food by 31%, and SM3 decreased its responding by 50%. Whereas responding for water had increased with increases in the frequency of the alternative food under the closed economy, the open economy produced no consistent changes in water responding or water consumption as the frequency of the alternative food source varied. This pattern of results suggests that responding for substitutable (or at least identical) commodities is not as strongly affected by the "economic conditions of daily consumption" (Hursh, 1978, p. 475) as is responding for complementary commodities. That is to say, responding for the constant food showed qualitatively similar changes under both open and closed economies, whereas responding for the water was affected differently by the open and closed economies as the frequency of the alternative food was varied.

What is it about the open economy that brought about such minimal effects on responding for water? One possibility is that the availability of postsession water increased the demand elasticity of water during the session (Hursh, 1980). Demand elasticity can be thought of as the degree to which consumption of a commodity is affected by changes in price for that commodity. If demand is elastic, then consumption is strongly influenced by changes in price. If, however, demand is inelastic, then consumption is relatively unaffected by changes in price. One of the factors influencing demand elasticity is the availability of substitutes (Allison, 1986). In the open economy the postsession water provided a substitute—albeit a temporally distant one—for the water available during the session, thus resulting in the increased demand elasticity of water. Stated differently, in the closed economy the monkeys worked to defend a certain "water balance" or ratio of water to food, thereby increasing responding for water when more food was available. In the open economy, however, the water balance did not have to be so strongly defended through responding because a constant daily intake was maintained via postsession access to water (Hursh, 1984).

It is worth noting that a complementary relationship has not always been obtained between food and water. Allison and Mack (1982) demonstrated that within a closed economy, food and water can serve as complements under some circumstances but can serve as substitutes under others. In one experiment, rats were permitted free access to food and water during a baseline phase. In subsequent phases, the rats continued to have free access to water, but food delivery was arranged through fixed-time (FT) schedules such that the total amount of food delivered was less than that consumed during the baseline phase. These conditions produced the familiar schedule-induced polydipsia: The rats consumed substantially greater quantities of water than they had during baseline and made a greater number of licks. Moreover, an interesting substitution effect was also evident: As total food intake was increased under the FT schedules (but kept below baseline levels), the total number of water licks decreased linearly. In terms of Allison's (1976) conservation model, water consumption rose above baseline because drinking had some substitute value for the experimentally suppressed eating behavior.

In their Experiment 4, Allison and Mack (1982) ascertained whether eating and drinking are mutually substitutable—even though drinking was shown to be substitutable for eating, such a result need not imply that eating is substitutable for drinking. To this end, rats were exposed to FT schedules of water delivery with food now freely available, following a baseline phase of free access to both the food and water. The FT schedules of water delivery restricted water intake below baseline levels. Unlike the first experiment, clear complementarity was evident: Food intake decreased as water intake decreased. According to Allison and Mack, these results indicate that eating and drinking are substitutable when eating is suppressed (increases in water intake can help alleviate hunger) but are complementary when drinking is suppressed (dry food cannot alleviate thirst).

Rachlin and Krasnoff (1983) confirmed this asymmetry in substitutability effects between food and water. They studied rats deprived of either food or water in an open economy. During 3-hr sessions, food-deprived rats had free access to water, but could have either free or restricted (via variable-time [VT] schedules) access to food. Similarly, water-deprived rats had free access to food, but access to water was either continuous or determined by VT schedules. With regard to their major findings, Rachlin and Krasnoff's results verified those of Allison and Mack (1982). Under conditions of food deprivation, rats spent more time drinking when food was restricted than when it was freely available, demonstrating polydipsia and thus a substitution of water for food. However, under conditions of water deprivation, rats did not evidence polyphagia (excessive eating), but instead spent slightly less time eating when water was restricted than when it was continuously available, thereby indicting complementarity between food and water.

Hursh (1978) suggested that responding controlled by nonsubstitutable commodities such as food and water is affected by economy type. However, Rachlin and Krasnoff (1983), with their use of an open economy, replicated the findings of Allison and Mack (1982), who employed a closed economy. That is, the relationship between food and water was determined by which one of the commodities was restricted below baseline levels, and not by economy type. In Hursh's experiment, the subjects' access to *both* commodities was restricted below baseline levels, and it is this difference (aside from the obvious species difference) that might make responding for nonsubstitutable commodities sensitive to type of economy.

Substitution effects between reinforcers need not occur only along some physiological dimension. In fact, substitutability has been demonstrated in situations in which it would be difficult to identify a common physiological need. In one such demonstration, Bernstein and Ebbesen (1978) studied human subjects living for several weeks in isolated laboratory environments. During an initial baseline period, the subjects were free to engage in a variety of activities (e.g., sewing, reading, candlemaking, and painting). Following the free baseline, access to one of the activities was restricted to below-baseline levels and was made contingent on engaging in another of the activities. Bernstein and Ebbesen found that substitution of other activities for the restricted activity was selective; that is, the additional time was not proportionately distributed among the nonrestricted activities but instead was focused on one or two of them. In some cases, time was redistributed to activities quite unlike the one that was restricted. For example, when access to sewing was restricted for 1 subject, there was a disproportionate increase in reading magazines. If this subject had redistributed her additional time to the nonrestricted activities in proportion to their baseline levels, the percentage of time spent reading magazines would have increased 5%, from 14% to 19% of her waking hours. However, this subject increased her magazine reading 13%, to a total of 27% of her waking hours.

In a similar demonstration (Burkhard, Rachlin, & Schrader, 1978), nursery school children were allowed to play freely with a variety of toys during a baseline period. For each child, a toy was then classified as high, medium, or low, based on the amount of time spent playing with it. Several weeks later, the children were studied under an experimental contingency in which only three toys, one each from the high, medium, and low categories, were available. Access to the high toy was restricted below baseline level, and was contingent on playing with either the low toy for one group or the medium toy for another group. For both groups, the third toy was freely available. Children in both groups increased above baseline levels the time spent playing with their respective instrumental toys, demonstrating the expected "Premackian" reinforcement effect. In addition, the group for whom the medium toy was freely available greatly increased the time spent playing with this toy; in fact, the time spent with it was equal to that of the group for whom playing with the medium toy was the instrumental response. Rachlin and Burkhard (1978) interpret this result as due to the substitution of the medium toy for the restricted high toy, much like the substitution of magazine reading for sewing shown by Bernstein and Ebbesen's (1978) subject.

The experiments reported by Bernstein and Ebbesen (1978) and Burkhard et al. (1978) serve to demonstrate that substitutes need not satisfy a common physiological need, nor are they necessarily related in any obvious way. Instead, substitution effects may have their basis in individual experience (Hursh & Bauman, 1987). For example, Allison and Mack (1982) have suggested that through classical conditioning, lever pressing might come to serve as a *learned* substitute for eating.

Although the results from additional studies demonstrating substitutability might not be terribly surprising, they do provide validity for the use of substitutability as a factor in accounting for reinforcement interactions. In one such experiment, Lea and Roper (1977) studied rats responding in a chamber with two compartments. In one compartment, mixed diet pellets were available under fixed-ratio schedules that ranged from FR 1 to FR 16 across conditions. In the second compartment, an alternative food source (either the identical mixed diet pellets or sucrose pellets), when it was available, could be obtained on an FR 8 schedule. Lea and Roper found that for hungry rats, mixed diet pellets were highly substitutable for an identical and concurrently available food. However, a concurrent source of sucrose pellets was not as highly substitutable for mixed diet pellets. These conclusions were drawn from differences in demand elasticity for mixed diet pellets when the concurrently available alternative was the identical food versus sucrose pellets. For example, as the price of the mixed diet pellets increased from FR 1 to FR 16, the number of mixed diet pellets obtained in the first compartment declined by approximately 79% when the concurrently available food was identical, whereas the number of mixed diet pellets obtained decreased by approximately 63% when the concurrently available food was sucrose pellets. Demand for the mixed diet pellets was least elastic when no alternative food source was available, as demonstrated by the roughly 45% decrease in obtained reinforcements across the same range of prices.

Some research, however, has generated results contrary to conventional wisdom. In one such case, Green and Rachlin (1991) studied rats in an open economy, choosing between pairs of reinforcers available under concurrent variable-ratio (VR) schedules. The pairs of reinforcers were food and water, food and electrical stimulation of the brain (EBS), and water and EBS. The procedure employed was that of Rachlin et al. (1976): For each pair of reinforcers, an income of total responses that varied across conditions was allotted, with sessions terminating once the total number of responses had been spent. In addition, each reinforcer in a pair was assigned a price, determined by a VR schedule. Subsequent conditions comprised income-compensated price changes. With respect to choices between food and water, the results generally confirmed those of Rachlin et al. (1976) (i.e., a highly nonsubstitutable relation was evident). Interestingly, food and EBS proved to be highly substitutable: When both EBS and food were available on a VR 15 schedule, all the rats preferred EBS to food. When EBS was made cheaper, the rats increased their "consumption" of EBS while decreasing their consumption of food. When food became the cheaper commodity, food consumption markedly increased and EBS consumption decreased dramatically. Although introductory psychology texts (e.g., Gleitman, 1991) report that when given a choice between food and EBS, hungry rats choose to self-stimulate "even though it literally brings starvation" (p. 97), Green and Rachlin clearly demonstrated that even a small increase in the price of EBS (from VR 15 to VR 30) dramatically decreased responding for EBS. Similarly, Hursh and Natelson (1981) have shown that rats' demand for EBS is highly elastic whereas demand for food is relatively inelastic, and Hollard and Davison (1971) have additional evidence to suggest that food and EBS are completely substitutable for pigeons.

Perhaps the most striking aspect of the Green and Rachlin (1991) results is that EBS also proved to be fairly substitutable for water, although food and water were not substitutable for each other. Based on these data, Green and Rachlin suggest that EBS may function as a general reinforcer—substitutable for other

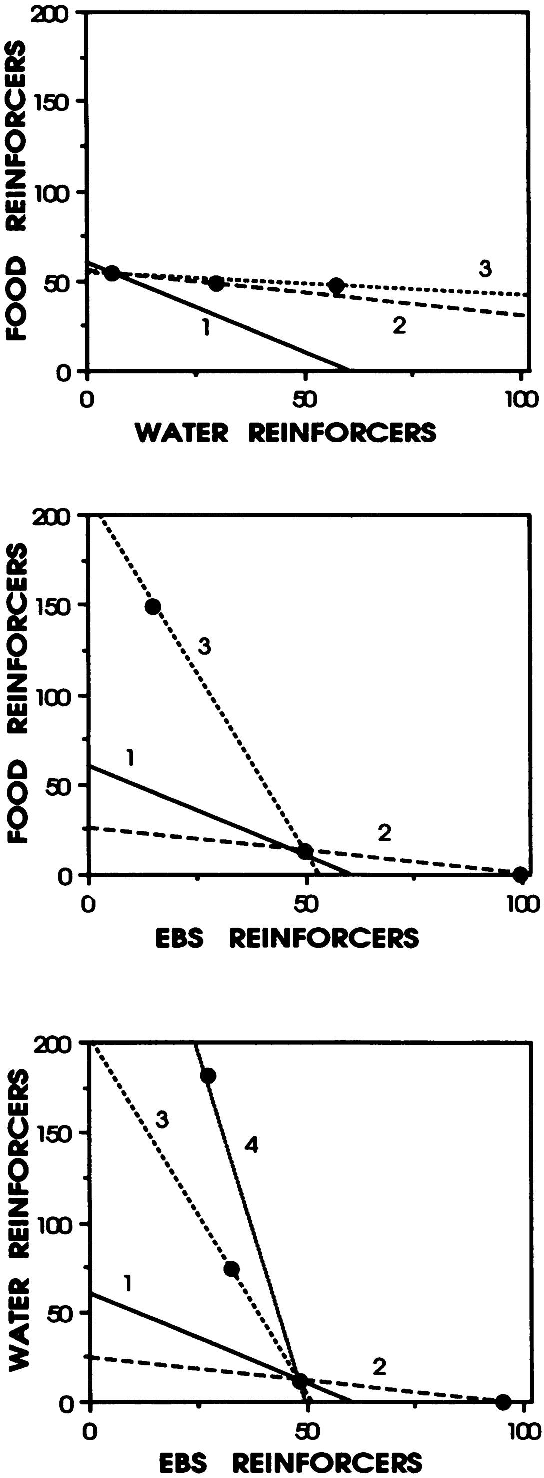

Fig. 3. Individual data from Rat A, showing the interactions between food and water, food and EBS, and water and EBS under a series of budget constraints. Each solid line represents a unique budget constraint, and each filled circle represents the combination of reinforcers obtained under that constraint. (Adapted from Green & Rachlin, 1991.)

goods that are not themselves substitutable—in much the same way that money functions as a general economic good in a human economy.

The individual data from Rat A (the only subject exposed to all experimental treatments) presented in Figure 3 depict the interactions Green and Rachlin (1991) found between food and water, food and EBS, and water and EBS. Each numbered line represents a budget constraint imposed by concurrent VR schedules for the two commodities and a total number of responses allotted. Each filled circle represents the combination of reinforcers obtained under that budget constraint. For example, in the food versus EBS graph (middle graph), when EBS and food were equally priced (Budget Line 1), EBS was strongly preferred over food. When EBS was made cheaper than food (Budget Line 2) Rat A responded almost exclusively for EBS. When prices were reversed so that food was made relatively cheaper, EBS made relatively more expensive, and income adjusted (Budget Line 3), Rat A increased consumption of food reinforcers 10-fold over its consumption of EBS reinforcers. These same dramatic changes in relative consumption as a function of income-compensated price changes are also evident in the water versus EBS (bottom) graph. However, changing the relative prices of food and water had substantially different effects on the consumption of those reinforcers (top graph); that is, even with sizable decreases in the price of water (Budget Lines 2 and 3), there was only a minor decrease in consumption of the now more expensive food.

Many of the studies reviewed to this point have made unique contributions to the psychological literature because they are, to some extent, experiments that could not have been conducted or interpreted without the consideration of economic factors. One such factor for which this may be particularly true is leisure, or nonresponding. An adequate discussion of leisure is beyond the scope of this paper, except to mention that a variety of studies (see Rachlin et al., 1981, and Schrader & Green, 1990, for reviews) indicate that under some conditions leisure can substitute for income (typically food for nonhuman subjects; e.g., Green, Kagel, & Battalio, 1982, 1987), and the degree of substitutability is affected by variables such as need (Green & Green, 1982), type of leisure activity available, and so forth.

SUBSTITUTABILITY AND THE MATCHING LAW

Baum (1974) proposed a generalized version of the matching law:

$$B_x/B_y = b(R_x/R_y)^s, \qquad (5)$$

where B, as before, represents the behavior allocated to alternatives x and y, R represents the reinforcers obtained from that behavior, and the constants b and s denote bias and sensitivity to those reinforcement alternatives. Bias reflects a systematic asymmetry between the alternatives, such as position or color preference for one of the two alternatives. A complete lack of bias would be the case in which $b = 1$. Sensitivity is manifest as the slope of the line that plots the logarithm of the behavior ratio B_x/B_y as a function of the logarithm of the reinforcement ratio R_x/R_y. When $s < 1$, the behavior is called undermatching (i.e., the subject overvalues the leaner schedule of reinforcement); when $s > 1$, the behavior is called overmatching (the subject overvalues the richer schedule of reinforcement). When the constants b and s both equal 1, the generalized matching equation reduces to Equation 2. These additional parameters allow Equation 5 to account for a greater variety of data from choice situations than does Equation 2 (Baum, 1979).

The vast majority of data described by the generalized matching law have been gathered in experiments that used qualitatively similar (indeed identical) reinforcers. Early on, Rachlin (1971) noted that in choices between qualitatively different reinforcers (such as between orange juice and grape juice), relative obtained reinforcement value would not equal relative amount consumed; yet if one assumes the matching relation to be true, then some other factor must be incorporated to preserve the relation between relative obtained reinforcement value and relative amount consumed for qualitatively different reinforcers. Additionally, as Baum (1974) has pointed out, deviations of s from unity are poorly understood. One attempt to understand these deviations has been made by Rachlin et al. (1981), who suggested that the exponent s in the generalized matching law should also be interpreted as substitutability. If this were so, s would approach unity for perfectly substitutable reinforcers, would approach negative infinity for perfect complements, and would be equal to zero for independent reinforcers. As an illustration, Rachlin et al. (1981) noted that in experiments with pigeons, rats, and monkeys choosing between food and water, s was approximately -10, whereas in choices between food and food or water and water, s was close to 1.

Rachlin et al.'s (1981) assessment of s as substitutability has not been universally accepted. Baum and Nevin (1981), for example, acknowledge that variation in s may, to some extent, incorporate choice between qualitatively different reinforcers, but find the substitutability interpretation to be premature. Baum (1974) noted that deviations of s from unity may be due in part to level of deprivation (and cites evidence to the effect that relative responding more closely matches relative reinforcement as level of deprivation is decreased; Herrnstein & Loveland, 1974, under multiple schedules; but see McSweeney, 1975, who did not find an effect of body weight on relative responding in concurrent schedules) or to poor discrimination between alternatives. For example, if an animal is responding on two manipulanda, each of which produces reinforcement, the inability to distinguish which manipulandum produced the reinforcer or the inability to distinguish between the reinforcers themselves would result in undermatching. This latter proposition does not seem compelling in the case of qualitatively different reinforcers, which certainly would be more readily discriminable than identical reinforcers. In addition to Baum's suggestions, Herrnstein (1974, 1981) argued that differing rates of satiation between qualitatively different reinforcers can account for observed deviations from matching.

The general proposal has been that qualitative differences between reinforcers can be treated in much the same way as differences in amount of the same reinforcer—that is to say, by introducing a constant scaling factor. For example, 1 g of food might have twice the value of 1 mL of water, given constant deprivation. We contend, not that this approach is wrong or even without merit, but rather that it is insufficient to deal with qualitatively different reinforcers.

The notion of accounting for qualitatively different reinforcers by introducing a scaling factor has received some empirical attention (e.g., Hollard & Davison, 1971). In an elegant demonstration of this approach, Miller (1976) conducted pairwise comparisons of pigeons' preferences for three different grains (hemp, buckwheat, and wheat). In the first comparison, pigeons chose between concurrent VI schedules delivering hemp and buckwheat, thereby assessing the scaling factor of the relative value of hemp to buckwheat. The second comparison was of wheat to buckwheat. This allowed the determination of the scaling factor of the relative value of wheat to buckwheat. The scaling of wheat and hemp each to buckwheat provided a common unit of value, and thus a prediction as to the relative value of wheat to hemp. Miller found that actual comparisons of wheat to hemp strongly supported the prediction based on scaling.

A problem with this type of analysis is that "value is assumed to be scalable independently of context" (Rachlin, Kagel, & Battalio, 1980, p. 355). The essential aspect missing in a scaling approach is well stated by Lancaster (1966, p. 134): "Goods in combination may possess characteristics different from those pertaining to goods separately." Miller selected reinforcers that were highly substitutable with respect to each other and were, therefore, easily amenable to scaling. Such might not be the case with nonsubstitutable reinforcers.

Consider another experiment in which pairwise comparisons of three different reinforcers were conducted. Green and Rachlin (1991) found food to be substitutable for EBS and water to be substitutable for EBS, but food and water were highly nonsubstitutable. Assume, for the sake of argument, that when food was compared to EBS, EBS was found to have a value of x and food a value of $1.1x$; that is, each food reinforcer was worth a little more than each EBS reinforcer. When water was compared to EBS, suppose that water was found to have a value of $0.9x$—each water reinforcer was worth slightly less than one EBS reinforcer. In accordance with the logic of scaling, knowing the values of food and water in the common currency of EBS allows us to determine that the relative value of food to water is 1.2; in other words, one food reinforcer should be worth marginally more than one water reinforcer. That the value of one commodity can be expressed in terms of its worth relative to another presupposes that those commodities can be traded for each other. However, the results Green and Rachlin obtained clearly contradict such a universal approach; food and water were consumed in fairly rigid proportion to one another. Thus, Miller (1976) found that, with a scaling factor, $A = C$ and $B = C$ implies $A = B$. Such a transitive result holds only with substitutable commodities. Without taking into account the degree of substitutability between commodities, the wrong prediction would be made with complements where, as Green and Rachlin showed, $A = C$ and $B = C$, but $A \neq B$.

Finally, consider behavior under concurrent ratio schedules of reinforcement. With identical reinforcers for each of the response alternatives, the matching law predicts exclusive preference for the cheaper alternative (i.e., the alternative with the lower ratio requirement) (Herrnstein & Vaughan, 1980). Indeed, such a result has been obtained (Green, Rachlin, & Hanson, 1983; Herrnstein & Loveland, 1975). However, nonexclusive responding is predicted and obtained when the reinforcers are not substitutable.

It is precisely because of results such as these that the notion of substitutability warrants inclusion in psychological models of choice in general and the matching law in particular. Although it is true that substitutability derives from a theory that assumes maximization of utility, one need not accept views of maximization in order to accept the notion of substitutability. Allison (1983) has noted that it is possible for an animal's behavior to obey the demand law without maximizing utility; that is to say, changes in price can produce inverse changes in consumption by some mechanism other than optimization (see Becker, 1962). The demand law can be derived without reference to utility. A similar argument can be made with regard to substitutability. It is possible to adopt an economic view of the fundamental interactions of reinforcers without necessarily adopting maximization theory. Granted that determination of scaling and substitutability both must be accomplished post hoc, substitutability has the advantage because it encompasses a broader range of possible interactions among reinforcers.

APPLICATIONS

The matching law is receiving increasing attention in applied behavior analysis (e.g., Epling & Pierce, 1983; McDowell, 1981, 1982, 1988; Myerson & Hale, 1984). Application of the matching law suggests two intervention strategies for the elimination of inappropriate behavior, in addition to standard treatment procedures of punishment and extinction. These are (a) increasing the rate of reinforcement for a concurrently available response (increasing R_y in Equation 1) and (b) increasing the rate of noncontingent reinforcement (increasing R_0 in Equation 4) (McDowell, 1981, 1982). Either of these interventions would have the effect of decreasing the occurrence of the inappropriate behavior, B_x (with R_x being the reinforcement for that behavior).

An example of the first intervention strategy was reported by Ayllon and Roberts (1974) with 5 fifth-grade boys who were disruptive in the classroom. Rather than attempting to decrease or eliminate the disruptive behaviors (B_x) by directly modifying the reinforcement for such behavior (R_x), Ayllon and Roberts instead instituted a token-reward system in which the children could earn points (R_y), exchangeable for a variety of activities and privileges, based upon their reading performance (B_y). When the points-for-reading-performance contingency was instituted, reading performance increased, as expected. Interestingly, B_x—the disruptive behavior—markedly decreased in frequency. When the reinforcement for reading performance was then withdrawn, disruption increased; the reinstatement of reinforcement (R_y) dramatically increased reading performance and nearly eliminated disruption.

In one clinical intervention exemplifying the second strategy, McDowell (1981) introduced a token-reinforcement contingency in which points were awarded for behaviors unrelated to the extreme oppositional behavior (refusal to follow instructions, aggressiveness, etc.) displayed by the client, a mildly retarded adult male. The oppositional behavior (B_x) appeared to be reinforced by attention (R_x) from the client's parents. The use of token rewards was chosen over other treatments aimed at directly decreasing reinforcement for the oppositional behavior (R_x), such as withdrawal of attention, because ignoring the client's outbursts could result in his becoming violent. The client earned points, later exchangeable for money, for activities such as reading, shaving, and helping with dinner. In other words, reinforcing alternative behavior is tantamount to increasing R_0 and should therefore decrease the incidence of the target oppositional behavior. Prior to implementation of the token-reward contingency, oppositional behavior occurred almost daily. During the first few weeks of intervention, oppositional behavior had decreased by approximately 80%, even though the reinforcement contingency for the oppositional behavior had not been changed.

Reinforcement for one behavior may influence the emission of other behavior in less than desirable ways. As an example, consider the token-reward system studied by Fisher et al. (1978). They examined the effects of different wages (tokens earned) for toothbrushing in a psychiatric population at a large state hospital, and measured the income (total tokens) earned weekly. As is apparent in Figure 4A, reinforcement for toothbrushing worked well: Income from toothbrushing increased as the number of tokens received for it increased from zero, to one, to five. However, there were significant effects of the changes in the wage for toothbrushing on the emission of other types of token-earning behavior, as can be seen in Figure 4B. The subjects decreased nontoothbrushing income earned, with greater reductions under the five- than under the one-token wage rate. As Fisher et al. state: "Thus, a wage for toothbrushing and, especially, a relatively high wage for toothbrushing discouraged patients from engaging in other token-reinforced, presumably therapeutic, behaviors" (p. 401). Clearly, then, a behavioral intervention occurs within a system, and attention to only the target behavior may blind the clinician, teacher, or parent to other, beneficial or detrimental, behavior changes (see Winkler & Burkhard, 1990).

The preceding interventions follow directly from the generalized matching law and do not necessitate an economic interpretation. However, our discussion of substitutability makes clear that interventions based on the matching law will be effective only to the extent that R_y and R_0 are substitutable for R_x. If R_y or R_0

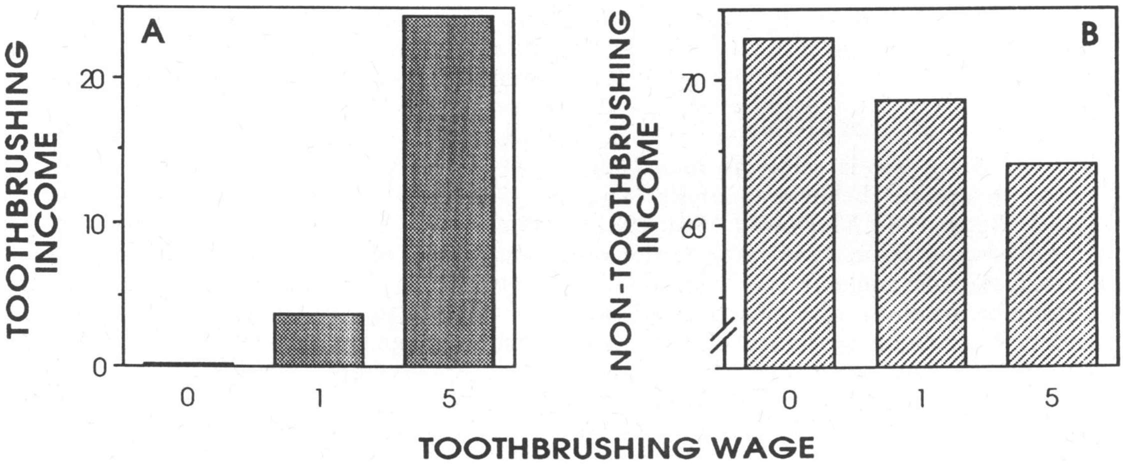

Fig. 4. Mean income earned from (A) toothbrushing and from (B) nontoothbrushing activities under wage conditions in which toothbrushing earned zero, one, or five tokens. (Adapted from Fisher et al., 1978.)

are nonsubstitutable for R_x, then the unfortunate consequence of increasing the alternative reinforcers (R_y or R_0) in the attempt to reduce inappropriate behavior may at best be an ineffective treatment (in the case of independent reinforcers) and may at worst result in increasing inappropriate behavior (if the reinforcers are complements). For example, it is not difficult to imagine the case of a harried parent who drops everything to play with a screaming child. If this parent also "spoils" the child by giving him many noncontingent toys (R_0), the result may be a child who screams a great deal because play time and toys tend to be consumed together—increasing the number of toys increases the demand for play time. The results from Fisher et al. (1978) noted above are also consistent with this view. Similarly, if R_x and R_0 are complements, then decreasing alternative reinforcers (R_0) may provide an effective means for decreasing the target response (B_x). Applied behavior analysts who do not take the time and effort to evaluate the substitutability of reinforcers in designing behavior-change programs do so at peril to their clients.

The concept of substitutability may also be relevant to an understanding of addictions. Stigler and Becker (1977) have proposed two types of addictions—positive and negative (see Herrnstein, 1990, for an alternative behavioral account of addictions). Positive addictions are acquired when demand for that good is elastic (i.e., equivalently priced substitutes are available) and when the price of that good decreases with increased consumption. Stigler and Becker give the following example: The more "good" music one listens to, the more good music is appreciated, thus effectively decreasing the "price" of listening to music—one begins to recognize themes, styles, and so forth, and so the music is not as difficult to follow. The result is an increase in music consumption because music is now cheap relative to other substitutable goods.

Negative addictions are acquired when demand for that good is inelastic (because equivalently priced substitutes are unavailable) and the price of that good increases with increased consumption. Demand, according to Stigler and Becker (1977), is not for the good itself, but for the satisfaction that good offers (i.e., "euphoria"). Euphoria is a good that presumably is largely inaccessible to those living in conditions of extreme poverty or neglect, except through consumption of drugs such as alcohol and cocaine. However, the more alcohol or cocaine is consumed, the less euphoria is obtained (this is what is meant by tolerance to a drug). Tolerance can be thought of as an effective increase in the price of the drug; consequently, consumption of the drug must increase to produce the initial degree of euphoria (see, however, Elsmore, Fletcher, Conrad, & Sodetz, 1980, for an indication that in baboons, demand for heroin is much more elastic than is demand for food). Because addicts' demand for drugs such as heroin and alcohol is inelastic, exogenous increases in price (e.g., decreasing the available supply or imposing harsh penalties for use) will have relatively little influence on consumption. Exogenous price increases, as Stigler and Becker note, affect only positively addictive commodities because demand for these is elastic. If Stigler and Becker's analysis is accurate, the implications for current social policy are enormous. (See Hursh, 1991, for a cogent discussion of drug abuse and public policy with regard to behavioral economic issues including substitutability.)

It is admittedly speculative to venture that there may be substitutability between such seemingly disparate reinforcers as social support and substance abuse. But in keeping with our general definition of substitutable commodities, we note that both social support and drug taking serve similar purposes—they reduce negative feelings and increase positive feelings. The apparent link between coping with unpleasant feelings and involvement in risky behavior (e.g., drug and alcohol consumption, cigarette smoking, problem eating) (Wills & Shiffman, 1985) suggests that social support and risky behavior may substitute for each other in times of emotional distress. Consequently, during times of hardship, social support from close personal relationships may be sought by those to whom it is available, whereas persons lacking such relationships may be more likely to engage in risky behavior. Furthermore, social support may provide an effective substitute for the drug use that is undertaken to alleviate loneliness; to the extent that they are related to one another (Newcomb & Bentler, 1986), social support, as a substitute for drug taking, may reduce loneliness and thus the likelihood of engaging in such risky behavior.

Prochaska and DiClemente (1985) have also noted the connection between unpleasant feelings and drug abuse. They state that "emotional distress is one of the most common reasons people relapse in attempts to overcome addictive behaviors" (p. 345). Social support may be effective in handling such distress and thereby provide an effective approach to the problem of relapse.

Of course, chemical substances are very powerful short-term reinforcers, whose reinforcing effects are immediate and thus quite effective. Less is understood about which components of social support are effective, let alone how best to implement it and educate people in its use (Thoits, 1986). Still, this seems to be a fertile area for continued research. (For a discussion of some of the research on social support and risk behavior, see Rehberg, 1992.)

CONCLUSIONS

We noted in an earlier section that determinations of the substitutability of reinforcers are made post hoc. Given that this is so, the concept of substitutability would seem to be of limited utility. The goal of any science, after all, is to adopt concepts that are predictive and explanatory as well as descriptive. There is no doubt that substitutability is descriptive, but can it in fact predict and explain extant and future findings?

As one example, consider the relationship between food and water. A number of studies with rats (Allison & Mack, 1982; Green & Rachlin, 1991; Rachlin & Krasnoff, 1983; Rachlin et al., 1976) have generally found food and water to be highly nonsubstitutable. This relationship is also true in primates (Hursh, 1978) and has been obtained, albeit not consistently, in pigeons (Battalio, Kagel, Rachlin, & Green, 1981). Similarly, the substitutable relationship between EBS and food is evident in both rats (Green & Rachlin, 1991) and pigeons (Hollard & Davison, 1971). That the interactions between food and water and between EBS and food hold across species lends a measure of generality, and therefore predictability, to notions of substitutability.

That one cannot predict, in the absence of additional information, how two reinforcers will interact for a given species does not diminish the validity of the concept of substitutability, just as the concept of reinforcement is not discredited when one cannot predict if an outcome will function as a reinforcer. However, the factors that affect substitutability, beyond the reinforcers themselves, should be predictable once delineated (just as rate, magnitude, and delay of reinforcement have predictable effects that are largely independent of the nature of the reinforcer). The work of Lea and Roper (1977) and analysis by Hursh and Bauman (1987) suggest that one of these factors is the temporal separation between alternatives, and this separation attenuates the degree of substitutability even in otherwise perfect substitutes. Hursh and Bauman's analysis compares demand curves generated under three different temporal situations: concurrent schedules, multiple schedules, and across conditions of the same experiment. These three situations are likened to comparing prices of identical items on the same shelf, comparing prices of identical items in different stores, and comparing prices of identical items over months of shopping, respectively. The demand curves (in which consumption of food from one alternative is analyzed as a function of its relative price when an alternative but identical food is present) reveal that the greater the temporal separation between identical commodities, the lower their substitutability.

In terms of the generalized matching law, one would predict that decreased substitutability would be manifest by decreases in the value of s as the temporal separation between alternatives increases. One way to increase the temporal separation between alternative reinforcers is to hold the relative rate of reinforcement constant across concurrent variable-interval schedules while decreasing the overall rate of reinforcement. Indeed, when Alsop and Elliffe (1988) studied pigeons responding under this procedure, they found that the value of s decreased as the overall rate of reinforcement was decreased. Additional confirmation of this prediction is found in the work of La Fiette and Fantino (1988), who similarly obtained lower values of s as the duration of the components in multiple VI schedules was increased (thereby increasing the temporal separation between reinforcement alternatives) when their subjects were studied in an open economy. Additionally, in a reanalysis of the data of Shimp and Wheatley (1971), La Fiette and Fantino calculated values of s that increased from 0.41 to 0.95 when equal component durations in a multiple schedule were decreased from 180 s to 10 s.

It would be unwise to place too much emphasis on this one example, especially in light of other evidence to the contrary. La Fiette and Fantino (1988), for example, obtained increasing values of s as component durations were increased in a closed economy. Nonetheless, this example does suggest the predictive utility of substitutability, which may be further refined in light of contradictory findings. Moreover, the effect of temporal separation on substitutability itself may in turn be modulated by the nature of the commodities in question; any temporal separation between goods that must be consumed immediately (such as heat) may produce any degree of substitutability between them.

Finally, the heuristic value of substitutability cannot be overemphasized. Notions of substitutability cause one to examine interactions among reinforcers that otherwise might not have been considered. Moreover, without an economic framework, researchers cannot predict an animal's future preference based solely on its current preference. This was vividly demonstrated in the studies of Green and Rachlin (1991) and Hursh and Natelson (1981), in which animals chose between food and brain stimulation. An additional example is provided by Elsmore et al. (1980), who found that when heroin-addicted baboons were offered periodic opportunities to choose between food and heroin infusion, the baboons were relatively indifferent between food and heroin when the intertrial interval was short. However, as the intertrial interval was increased (effectively increasing the prices of food and heroin equally), the baboons gave up heroin infusions but not food, indicating that demand for food, compared to that for heroin, is largely inelastic.

The matching law was developed to account for choice between qualitatively identical reinforcers, and in that domain it fares quite well. But it can be easily argued that choices in the world beyond the laboratory are rarely made between identical outcomes that differ only with respect to magnitude, frequency, or delay. In short, many of our choices are between oranges and tennis balls, not necessarily between Coke and Pepsi. The implicit assumption of the matching law is that *all* reinforcers are perfectly substitutable. Results with qualitatively different reinforcers are therefore accommodated by appeal to a scaling factor. But, as we have seen, this approach works only when the reinforcers are in fact substitutable. When the reinforcers are not substitutable, as is the case with food and water, appeal is then made to, say, differential rates of satiation as an explanation. Furthermore, it is only with the matching law's assumption of perfect substitutability that all alternative sources of reinforcement are predicted to affect B_x equivalently, and thus can be subsumed under the single term R_0. The economic concept of substitutability as a continuum of possible interactions among reinforcers explicitly denies this assumption, thereby generating new research, interpretation, and analysis.

REFERENCES

Allison, J. (1976). Contrast, induction, facilitation, suppression, and conservation. *Journal of the Experimental Analysis of Behavior,* **25,** 185–198.

Allison, J. (1983). Behavioral substitutes and complements. In R. L. Mellgren (Ed.), *Animal cognition and behavior* (pp. 1–30). Amsterdam: North-Holland.

Allison, J. (1986). Economic interpretations of animal experiments. In A. J. MacFadyen & H. W. MacFadyen (Eds.), *Economic psychology: Intersections in theory and application* (pp. 219–245). Amsterdam: Elsevier.

Allison, J. (1989). The nature of reinforcement. In S. B. Klein & R. R. Mowrer (Eds.), *Contemporary learning theories: Instrumental conditioning theory and the impact of biological constraints on learning* (pp. 13–39). Hillsdale, NJ: Erlbaum.

Allison, J., & Mack, R. (1982). Polydipsia and autoshaping: Drinking and leverpressing as substitutes for eating. *Animal Learning & Behavior,* **10,** 465–475.

Allison, J., Miller, M., & Wozny, M. (1979). Conservation in behavior. *Journal of Experimental Psychology: General,* **108,** 4–34.

Alsop, B., & Elliffe, D. (1988). Concurrent-schedule performance: Effects of relative and overall reinforcer rate. *Journal of the Experimental Analysis of Behavior,* **49,** 21–36.

Ayllon, T., & Roberts, M. D. (1974). Eliminating discipline problems by strengthening academic performance. *Journal of Applied Behavior Analysis,* **7,** 71–76.

Battalio, R. C., Kagel, J. H., Rachlin, H., & Green, L. (1981). Commodity-choice behavior with pigeons as subjects. *Journal of Political Economy,* **89,** 67–91.

Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior,* **22,** 231–242.

Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior,* **32,** 269–281.

Baum, W. M., & Nevin, J. A. (1981). Maximization theory: Some empirical problems. *Behavioral and Brain Sciences,* **4,** 389–390.

Baumol, W. J. (1972). *Economic theory and operations analysis* (3rd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Becker, G. S. (1962). Irrational behavior and economic theory. *Journal of Political Economy,* **70,** 1–13.

Berlyne, D. E. (1969). The reward-value of indifferent stimulation. In J. T. Tapp (Ed.), *Reinforcement and behavior* (pp. 178–214). New York: Academic Press.

Bernstein, D. J., & Ebbesen, E. B. (1978). Reinforcement and substitution in humans: A multiple-response analysis. *Journal of the Experimental Analysis of Behavior,* **30,** 243–253.

Burkhard, B., Rachlin, H., & Schrader, S. (1978). Reinforcement and punishment in a closed system. *Learning and Motivation,* **9,** 392–410.

Elsmore, T. F., Fletcher, G. V., Conrad, D. G., & Sodetz, F. J. (1980). Reduction of heroin intake in baboons by an economic constraint. *Pharmacology Biochemistry and Behavior,* **13,** 729–731.

Epling, W. F., & Pierce, W. D. (1983). Applied behavior analysis: New directions from the laboratory. *Behavior Analyst,* **6,** 27–37.

Fisher, E. B., Jr., Winkler, R. C., Krasner, L., Kagel, J., Battalio, R. C., & Basmann, R. L. (1978). Economic perspectives in behavior therapy: Complex interdependencies in token economics. *Behavior Therapy,* **9,** 391–403.

Gleitman, H. (1991). *Psychology* (3rd ed.). New York: Norton.

Green, J. K., & Green, L. (1982). Substitution of leisure for income in pigeon workers as a function of body weight. *Behaviour Analysis Letters,* **2,** 103–112.

Green, L., Kagel, J. H., & Battalio, R. C. (1982). Ratio schedules of reinforcement and their relation to economic theories of labor supply. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 395–429). Cambridge, MA: Ballinger.

Green, L., Kagel, J. H., & Battalio, R. C. (1987). Consumption-leisure tradeoffs in pigeons: Effects of changing marginal wage rates by varying amount of reinforcement. *Journal of the Experimental Analysis of Behavior,* **47,** 17–28.

Green, L., & Rachlin, H. (1991). Economic substitutability of electrical brain stimulation, food, and water. *Journal of the Experimental Analysis of Behavior,* **55,** 133–143.

Green, L., Rachlin, H., & Hanson, J. (1983). Matching and maximizing with concurrent ratio-interval schedules. *Journal of the Experimental Analysis of Behavior,* **40,** 217–224.

Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior,* **4,** 267–272.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior,* **13,** 243–266.

Herrnstein, R. J. (1974). Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior,* **21,** 159–164.

Herrnstein, R. J. (1981). A first law for behavioral analysis. *Behavioral and Brain Sciences,* **4,** 392–395.

Herrnstein, R. J. (1990). Rational choice theory: Necessary but not sufficient. *American Psychologist,* **45,** 356–367.

Herrnstein, R. J., & Loveland, D. H. (1974). Hunger and contrast in a multiple schedule. *Journal of the Experimental Analysis of Behavior,* **21,** 511–517.

Herrnstein, R. J., & Loveland, D. H. (1975). Maximizing and matching on concurrent ratio schedules. *Journal of the Experimental Analysis of Behavior,* **24,** 107–116.

Herrnstein, R. J., & Vaughan, W., Jr. (1980). Melioration and behavioral allocation. In J. E. R. Staddon (Ed.), *Limits to action: The allocation of individual behavior* (pp. 143–176). New York: Academic Press.

Hollard, V., & Davison, M. C. (1971). Preference for qualitatively different reinforcers. *Journal of the Experimental Analysis of Behavior,* **16,** 375–380.

Hull, C. L. (1943). *Principles of behavior: An introduction to behavior theory.* New York: Appleton-Century-Crofts.

Hursh, S. R. (1978). The economics of daily consumption controlling food- and water-reinforced responding. *Journal of the Experimental Analysis of Behavior,* **29,** 475–491.

Hursh, S. R. (1980). Economic concepts for the analysis of behavior. *Journal of the Experimental Analysis of Behavior,* **34,** 219–238.

Hursh, S. R. (1984). Behavioral economics. *Journal of the Experimental Analysis of Behavior,* **42,** 435–452.

Hursh, S. R. (1991). Behavioral economics of drug self-administration and drug abuse policy. *Journal of the Experimental Analysis of Behavior,* **56,** 377–393.

Hursh, S. R., & Bauman, R. A. (1987). The behavioral analysis of demand. In L. Green & J. H. Kagel (Eds.), *Advances in behavioral economics* (Vol. 1, pp. 117–165). Norwood, NJ: Ablex.

Hursh, S. R., & Natelson, B. H. (1981). Electrical brain stimulation and food reinforcement dissociated by demand elasticity. *Physiology & Behavior,* **26,** 509–515.

Kagel, J. H., Battalio, R. C., Rachlin, R., Green, L., Basmann, R. L., & Klemm, W. R. (1975). Experimental studies of consumer demand behavior using laboratory animals. *Economic Inquiry,* **13,** 22–38.

La Fiette, M. H., & Fantino, E. (1988). The effects of component duration on multiple-schedule performance in closed and open economies. *Journal of the Experimental Analysis of Behavior,* **50,** 457–468.

Lancaster, K. J. (1966). A new approach to consumer theory. *Journal of Political Economy,* **74,** 132–157.

Lea, S. E. G., & Roper, T. J. (1977). Demand for food on fixed-ratio schedules as a function of the quality of concurrently available reinforcement. *Journal of the Experimental Analysis of Behavior,* **27,** 371–380.

Logan, F. A. (1960). *Incentive: How the conditions of reinforcement affect the performance of rats.* New Haven, CT: Yale University Press.

McDowell, J. J. (1981). On the validity and utility of Herrnstein's hyperbola in applied behavior analysis. In C. M. Bradshaw, E. Szabadi, & C. F. Lowe (Eds.), *Quantification of steady-state operant behaviour* (pp. 311–324). Amsterdam: Elsevier.

McDowell, J. J. (1982). The importance of Herrnstein's mathematical statement of the law of effect for behavior therapy. *American Psychologist,* **37,** 771–779.

McDowell, J. J. (1988). Matching theory in natural human environments. *Behavior Analyst,* **11,** 95–109.

McSweeney, F. K. (1975). Concurrent schedule responding as a function of body weight. *Animal Learning & Behavior,* **3,** 264–270.

Miller, H. L., Jr. (1976). Matching-based hedonic scaling in the pigeon. *Journal of the Experimental Analysis of Behavior,* **26,** 335–347.

Myerson, J., & Hale, S. (1984). Practical implications of the matching law. *Journal of Applied Behavior Analysis,* **17,** 367–380.

Newcomb, M. D., & Bentler, P. M. (1986). Loneliness and social support: A confirmatory hierarchical analysis. *Personality and Social Psychology Bulletin,* **12,** 520–535.

Premack, D. (1965). Reinforcement theory. In D. Levine (Ed.), *Nebraska symposium on motivation* (Vol. 3, pp. 123–180). Lincoln: University of Nebraska Press.

Prochaska, J. O., & DiClemente, C. C. (1985). Common processes of self-change in smoking, weight control, and psychological distress. In S. Shiffman & T. A. Wills (Eds.), *Coping and substance use* (pp. 345–363). Orlando, FL: Academic Press.

Rachlin, H. (1971). On the tautology of the matching law. *Journal of the Experimental Analysis of Behavior,* **15,** 249–251.

Rachlin, H. (1989). *Judgment, decision, and choice: A cognitive/behavioral synthesis.* New York: Freeman.

Rachlin, H., Battalio, R., Kagel, J., & Green, L. (1981). Maximization theory in behavioral psychology. *Behavioral and Brain Sciences,* **4,** 371–417 (includes commentary).

Rachlin, H., & Burkhard, B. (1978). The temporal triangle: Response substitution in instrumental conditioning. *Psychological Review,* **85,** 22–47.

Rachlin, H., Green, L., Kagel, J. H., & Battalio, R. C. (1976). Economic demand theory and psychological studies of choice. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 10, pp. 129–154). New York: Academic Press.

Rachlin, H., Kagel, J. H., & Battalio, R. C. (1980). Substitutability in time allocation. *Psychological Review,* **87,** 355–374.

Rachlin, H., & Krasnoff, J. (1983). Eating and drinking: An economic analysis. *Journal of the Experimental Analysis of Behavior,* **39,** 385–404.

Rehberg, H. R. (1992). *Social integration, stress, and the consolidation of risky lifestyle behavior during the college years.* Unpublished doctoral dissertation, Washington University, St. Louis.

Samuelson, P. A. (1974). Complementarity: An essay on the 40th anniversary of the Hicks-Allen revolution in demand theory. *Journal of Economic Literature,* **12,** 1255–1289.

Schrader, S. M., & Green, L. (1990). The economics of leisure in psychological studies of choice. In L. Green & J. H. Kagel (Eds.), *Advances in behavioral economics* (Vol. 2, pp. 226-252). Norwood, NJ: Ablex.

Schwartz, B. (1989). *Psychology of learning and behavior* (3rd ed.). New York: Norton.

Shimp, C. P., & Wheatley, K. L. (1971). Matching to relative reinforcement frequency in multiple schedules with a short component duration. *Journal of the Experimental Analysis of Behavior,* **15,** 205–210.

Stigler, G. J., & Becker, G. S. (1977). De gustibus non est disputandum. *American Economic Review,* **67,** 76–90.

Thoits, P. A. (1986). Social support as coping assistance. *Journal of Consulting and Clinical Psychology,* **54,** 416–423.

Timberlake, W. (1980). A molar equilibrium theory of learned performance. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 14, pp. 1–58). New York: Academic Press.

Timberlake, W. (1984). Behavior regulation and learned performance: Some misapprehensions and disagreements. *Journal of the Experimental Analysis of Behavior,* **41,** 355–375.

Timberlake, W., & Allison, J. (1974). Response deprivation: An empirical approach to instrumental performance. *Psychological Review,* **81,** 146–164.

Wills, T. A., & Shiffman, S. (1985). Coping and substance use: A conceptual framework. In S. Shiffman & T. A. Wills (Eds.), *Coping and substance use* (pp. 3–24). Orlando, FL: Academic Press.

Winkler, R. C., & Burkhard, B. (1990). A systems approach to behavior modification through behavioral economics. In L. Green & J. H. Kagel (Eds.), *Advances in behavioral economics* (Vol. 2, pp. 288–315). Norwood, NJ: Ablex.

Received April 17, 1992
Final acceptance November 24, 1992