Chapter 8

# THE TRANSLATIONAL UTILITY OF BEHAVIORAL ECONOMICS: THE EXPERIMENTAL ANALYSIS OF CONSUMPTION AND CHOICE

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> An adequate science of behavior should supply a satisfactory account of the individual behavior which is responsible for the data of economics in general. (Skinner, 1953, p. 400)

More than a decade ago, E. O. Wilson (1998), the founder of sociobiology, an expert in ant societies, and a specialist in evolution, argued that consilience would advance an interdisciplinary and unified science. The term *consilience* was borrowed from the 19th-century historian and philosopher of science William Whewell (1794–1866). Whewell posited that in the rhetoric of scientific discourse, statements of empirical truth are more convincing if three criteria are met: prediction, coherence, and consilience. In this terminology, coherence extends well-established functional relations to other observations without ad hoc modification, and consilience extends scientific propositions about mechanisms and determinants to phenomena and investigative methodologies different from those originally contemplated (Snyder, 2009).

The relatively new field of behavioral economics may represent an example of consilience in which concepts from microeconomic theory are extended to the study of consumption by a range of species in the laboratory and the concepts of operant conditioning are extended to an understanding of demand for economic commodities. The blending of behavioral principles with microeconomic theory has been a fruitful area of research (e.g., Kagel, Battalio, & Green, 1995) and has provided a translational framework for extending principles derived from laboratory studies to an understanding of consumer choice observed in whole communities.

Economics and behavioral psychology have several points of convergence. One is a common interest in the value of goods, defined as reinforcers by the behaviorist and as objects of scarce consumption by economists. A second point of convergence is an interest in the process of choice: for the economist, the allocation of limited resources for the consumption of alternative goods (consumer choice), and for the behaviorist, the division of operant behavior among competing reinforcers. One area of divergence is that behavioral economists in the operant tradition have focused very little on hypothetical economic concepts, such as utility functions, indifference curves, and optimal choices. Instead, research efforts have focused on understanding the environmental factors affecting (a) overall levels of behavior that is instrumental in obtaining or consuming a variety of commodities in closed economic systems (Bickel, DeGrandpre, Higgins, & Hughes, 1990; Bickel, DeGrandpre, Hughes, & Higgins, 1991; Foltin, 1992; Hursh, 1984; Lea, 1978; Lea & Roper, 1977; Rashotte & Henderson, 1988) and (b) the allocation of behavioral resources among available reinforcers (Hursh, 1980, 1984; Hursh & Bauman, 1987; Madden, Smethells, Ewan, & Hursh, 2007a, 2007b).

Behavioral economics, as practiced by students of operant conditioning and behavior analysis, has

The writing of this chapter was supported by National Institute on Drug Abuse Grant RO1 DA029605 awarded to Gregory J. Madden.

DOI: 10.1037/13938-008
*APA Handbook of Behavior Analysis: Vol. 2. Translating Principles Into Practice,* G. J. Madden (Editor-in-Chief)

borrowed concepts from microeconomics, especially consumer demand theory and labor supply theory (Allison, 1983; Allison, Miller, & Wozny, 1979; Lea, 1978; Rachlin, Green, Kagel, & Battalio, 1976; Staddon, 1979; see Watson & Holman, 1977, for a review of relevant microeconomic theory). When applied in laboratory experiments, economic concepts are operationalized in special ways that build on more fundamental behavioral processes, such as reinforcement, discrimination, differentiation, and the like. These experiments have directed researchers' attention to new phenomena previously ignored and new functional relations previously unnamed. In this chapter, we apply behavioral economics to the analysis of consumption of various reinforcers and the responding that produces that consumption. We begin the chapter by providing a primer for understanding behavioral economic concepts that may subsequently be applied to understanding a range of behaviors in the laboratory and clinical setting. We provide examples of both present and potential translations of these basic science findings to improving the human condition.

## CONSUMER DEMAND

One of the principal areas of economic study is consumer demand; that is, the purchasing activities of the consumer and how they are affected by variables such as price, income, and the variety of goods available in the marketplace. Several basic laboratory researchers have conceptualized the operant behavior of their animal subjects as the behavior of a consumer (e.g., Allison, 1983; Collier, Hirsch, & Hamlin, 1972; Hursh, 1980). When the experimenter manipulates the schedule of reinforcement, he or she is acting as a supplier who sets the price of the commodity and then determines how much of the commodity the consumer will purchase at that price.

The simplest law of economics is the demand law, which states that as the price of a commodity increases, consumption of that commodity will decline. In the operant conditioning laboratory, behavioral economists operationalize price as a cost–benefit ratio; for example, three food pellets (benefit) for every three responses (cost) is a 3:3 ratio = 1. This is referred to as the unit price of the reinforcer, something that is often printed on price displays in U.S. grocery stores (e.g., the unit price of dried pasta may be $0.10 per ounce). The simplest test of the demand law would be to measure consumption when food is available at a low unit price (one pellet per response) and then again at a higher price (e.g., one pellet per 10 responses). Such laboratory tests generally support the demand law when rats are lever pressing for food, water, fat, electronic brain stimulation, and a variety of drugs (e.g., Bickel et al., 1990; Collier et al., 1972). Likewise, increasing the price of the reinforcer generally decreases pigeons' food consumption (e.g., Madden, Dake, Mauel, & Rowe, 2005) and humans' cigarette smoking (e.g., Bickel & Madden, 1999a).

As any grocer will tell you, changing the unit price of a reinforcer may be accomplished by either increasing the cost of obtaining the reinforcer or decreasing the benefits of the reinforcer (e.g., selling an ounce less dried pasta at the same price). In the laboratory, cost is typically quantified by the number of responses the subject must emit per reinforcer, but it could also be quantified as effort expended per reinforcer (e.g., time integral of force; Zarcone, Chen, & Fowler, 2009), time to a reinforcer (e.g., Tsunematsu, 2000), or a commodity loss after each response (e.g., a response–cost contingency), to name just a few cost dimensions. For humans, the cost component may also be specified as the amount of money paid per reinforcer (money being a medium by which past labor is exchanged for present goods and services). The benefit component of unit price refers to the amount of the reinforcer obtained (e.g., grams of food, dose of drug).

Before proceeding much further it is important to note that the demand law applies to total consumption. From a behavioral economic perspective, consumption is a fundamental dependent variable, which contrasts with much operant research that takes response-derived measures (e.g., response rate) as fundamental and procedurally excludes the possibility of meaningfully measuring consumption. In typical studies of operant conditioning, total consumption is determined by the experimenter rather than by the subject. That is, the experimenter caps total consumption in each session, and subjects usually run into this cap. Although this strategy eliminates within- and between-session changes in motivation that may influence response-derived

measures, it makes it impossible to study how consumption is affected by price constraints such as those found in the natural environment.

To measure the effects of a broad array of prices on consumption of a reinforcer, one must meaningfully measure consumption of the reinforcer. Hursh (1980, 1984, 1993) proposed that consumption be measured in terms of total daily intake of the reinforcer (e.g., milligrams of food, milliliters of water, or number of injections of a specific dose of a drug). This measure maps well to topics of translational interest such as total calories of food consumed per day among dieters (a seemingly more useful measure than rate of caloric intake during a set period of time). To evaluate the effects of a broad array of price increases on consumption, one must have a baseline measure of consumption when access to the reinforcer is relatively unconstrained. For example, a researcher might place a laboratory rat in an operant chamber with the contingency that a single lever press will deliver one 45-milligram food pellet. Here the price of food is very low: one lever press (cost) for one pellet (benefit), and the unit price equals 1. Setting a low price is important, but one must also not constrain consumption by placing a within-session cap on earnings. To measure unconstrained consumption, the session must be long enough that peak consumption may be achieved (e.g., when satiety halts further consumption within the session). In our experience with rats and pigeons working for food or water reinforcers, peak consumption may be reached by programming 11-hour sessions.

To illustrate the importance of measuring peak consumption, consider a hypothetical study in which consumption is artificially capped by the experimenter at 100 pellets. Had the session continued for 11 hours, peak consumption would have come in at 800 pellets. Thus, the experimenter has seriously underestimated unconstrained consumption. He or she will also be unable to detect the effects of any price increases until the price is sufficiently high that it reduces consumption to less than 100 pellets. For example, if the experimenter increases the unit price of food from one to 20 lever presses and the rat continues to consume 100 pellets, the experimenter will have missed the opportunity to see that in a long-duration session, the unit price increase from one to 20 would have decreased consumption from 800 to 500 pellets. Because consumption of naturally occurring reinforcers is most often not artificially capped by an outside force, conducting long-duration sessions provides a more appropriate model of consumer demand in the natural economy.

## Demand Curves

When consumption has been measured across a wide range of prices, the data are plotted as a demand curve with consumption on the *y*-axis and price along the *x*-axis. The demand curve shown in Figure 8.1 is typical of the relation between price and consumption in rats (e.g., Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988), pigeons (e.g., Madden et al., 2005), monkeys (e.g., Hursh, 1984), and humans (e.g., Bickel & Madden, 1999a). Moreover, the general shape of the demand curve is observed regardless of the reinforcer type (e.g., Madden et al., 2007a, 2007b), including a wide variety of drug reinforcers (Bickel et al., 1990, 1991; Hursh & Silberberg, 2008).

Demand curves are usually graphed on logarithmic axes because it facilitates a visual and quantitative

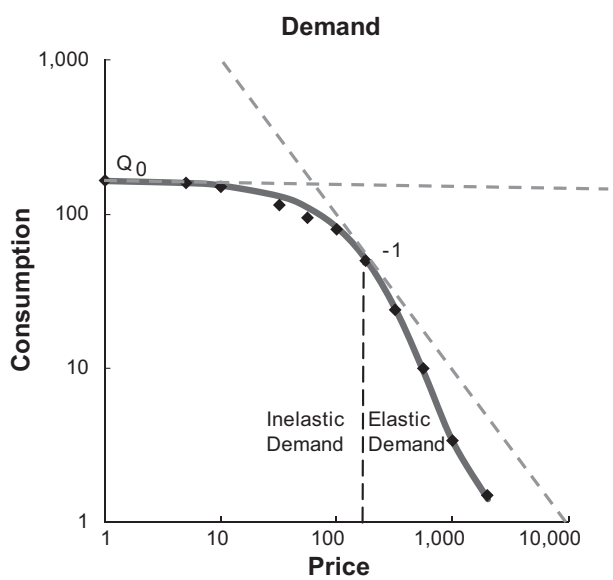



**FIGURE 8.1. Diagrammatic demand curve showing the usual shape and increasing elasticity across the demand curve. The vertical line marks the point of unit elasticity (slope = −1), which is the transition from inelastic to elastic demand. The level of demand is denoted as the *y*-intercept or the quantity consumed at zero price—$Q_0$.**

analysis of the proportional relation between changes in consumption and changes in price. A measure of the change in consumption that accompanies a price change is price elasticity of demand. When the decrease in consumption is proportionally less than the increase in price, the slope of the double-logarithmic demand curve is more shallow than −1. Across this range of price increases, demand is described as inelastic. When response output and rate of reinforcement have a direct relation (e.g., on a fixed-ratio [FR] schedule of reinforcement), inelastic demand reflects an increase in response expenditure in the face of the price increase. For example, in the 1970s when the price of gasoline in the United States increased from $0.33 per gallon to more than $1.00 per gallon, consumption decreased by only 10%, whereas average household expenditures on gasoline increased by more than 250%. Such inelastic demand reflects consumers' tendency to defend their consumption of a valuable commodity. Other commodities, such as luxury goods (unnecessary for survival) or goods with many substitutes (e.g., one brand of peanut butter), have more steeply sloping demand curves. When consumption of such goods declines proportionally more than the price of the good increases (slope steeper than −1) demand is described as elastic and consumption is highly sensitive to price. Here, response output (e.g., spending) declines with price increases.

The difference in demand between inelastic and elastic goods is easily demonstrated in a controlled laboratory setting. For example, Figure 8.2 depicts monkeys' average consumption of two reinforcers under conditions of increasing price, each studied in separate experimental sessions (Hursh, 1984, 1993). In one condition, food was available across a range of prices (from 10 to 372 lever presses per food pellet) with saccharin-sweetened water available at a constant low cost of 10 responses. In a similar condition, saccharin-sweetened water was available at the same range of prices and food was available at a constant cost of 10 responses. To ensure that demand for saccharin alone was being measured, an alternative source of unsweetened water was freely available. As may be seen in the left panel of Figure 8.2, demand for saccharin shifted from inelastic (shallow demand curve) to elastic (steep demand curve) at a much lower price than did demand for food. The price at which consumption of each commodity shifts from inelastic to elastic demand is labeled $P_{max}$ and is marked by a dashed vertical line in Figure 8.2. As a corollary to the differences in the demand curves, the number of responses emitted per day in the food reinforcement sessions increased over a broad range of prices whereas responding for

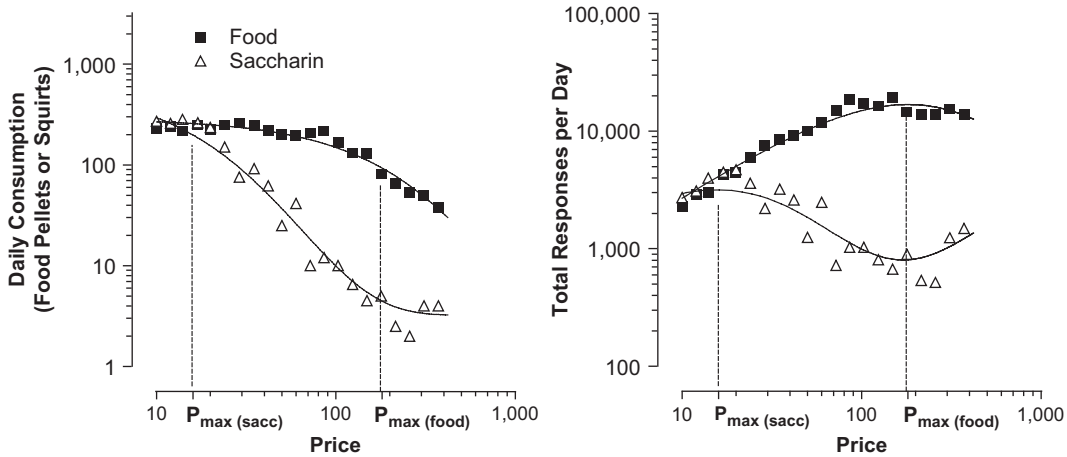



FIGURE 8.2. Left: Two demand curves for rhesus monkeys working for either food or saccharin-sweetened water. The demand functions show the total number of reinforcers consumed each day under a series of fixed-ratio schedules (prices) that ranged from fixed-ratio 10 to fixed-ratio 372. Data from Hursh and Silberberg (2008). Right: Daily output of responding that accompanied the levels of consumption shown in the left panel. The curves were fit with an exponential equation.

saccharin generally decreased over the same range. Note that peak response output per day occurs at $P_{max}$; at higher prices, spending tends to decline with price increases.

## Reinforcer Value

The differences in the demand curves shown in Figure 8.2 might be described heuristically as differences in reinforcer value. Because demand for food was more inelastic than demand for sucrose, it would appear that food was the relatively more valuable of the two reinforcers. Said another way, food appears to be a more effective reinforcer. Measuring differences in reinforcer value or efficacy has practical utility. For example, if one could quantify the value of a range of reinforcers, then one could arrange the most effective reinforcer to be delivered contingent on desired behavior such as drug abstinence (see Chapter 19, this volume) or in the establishment of adaptive behavior designed to replace severe problem behavior (see Chapter 14, this volume). We outline other examples of the practical utility of quantifying reinforcer value later in the chapter.

A common approach to evaluating the reinforcing efficacy of a consequence is to measure the ability of the consequence to maintain behavior under different experimental conditions (e.g., Griffiths, Brady, & Bradford, 1979). Many experimental conditions have been developed for this purpose; prominent among these are choice preparations, progressive-ratio (PR) schedules, and behavioral momentum–based evaluations of resistance to change. If reinforcer X is more valuable than reinforcer Y, then X should be preferred over Y, X should maintain behavior at a high response requirement whereas Y does not, and X-maintained behavior should be less susceptible to disruption than Y-maintained behavior.

However, inconsistencies across different experimental conditions are common. For example, Roane, Lerman, and Vorndran (2001) assessed preference rankings of four individuals with developmental disabilities as they chose between various tangible items. Two equally ranked and highly preferred items were then made available individually according to a PR schedule. Under a PR schedule, the number of operant responses required per reinforcer increases after each obtained reinforcer. Despite equal preference rankings in the choice preparation, under the PR schedule one reinforcer reliably maintained behavior at a high response requirement at which no behavior was maintained by the other reinforcer. Using the behavioral economic language introduced thus far, demand for one reinforcer proved to be more price inelastic than the other despite similar rankings in a preference assessment. Given this, and similar examples of inconsistencies across different experimental conditions (e.g., Bickel & Madden, 1999b; Elsmore, Fletcher, Conrad, & Sodetz, 1980; Jacobs & Bickel, 1999; Johnson & Bickel, 2006; Madden, Bickel, & Jacobs, 2000), several researchers have suggested that one or more properties of the demand curve may prove a useful measure of the value of a reinforcer (Bickel, DeGrandpre, & Higgins, 1993; Bickel & Madden, 1999b; Bickel, Marsch, & Carroll, 2000; Hursh & Winger, 1995; Roane et al., 2001).

The most recent of these suggestions was provided by Hursh and Silberberg (2008). They pointed out three problems with more traditional measures of reinforcer efficacy. First, response rate is an inappropriate measure of reinforcer value because it can easily be affected by contingencies of reinforcement (e.g., differential reinforcement of low or high rates). Second, choice experiments conducted in the tradition of Herrnstein's (1970) matching law have not manipulated directly important economic variables such as income and price and, therefore, have not contacted inconsistencies in preference that would disqualify it as a measure of reinforcer value. Third, a behavioral momentum approach to reinforcer value requires that measures of momentum be independent of baseline rates of behavior; however, some evidence has suggested that this requirement is not met (Nevin, Grace, Holland, & McLean, 2001). To this could be added the critique that behavioral momentum is primarily affected by Pavlovian (stimulus–stimulus) rather than operant (response–consequence) relations and, therefore, is an inappropriate measure of the value of an operant reinforcer.

Arguing in the affirmative, Hursh and Silberberg (2008) suggested that the value of a reinforcer is

reflected not only in its beneficial[1] characteristics but in its associated costs. This point was made in an experiment by Madden et al. (2007a) in which rats chose between food pellets and small amounts of a fat solution. At low prices, rats consumed both commodities with a modest preference for food. Thus, when the cost of the two reinforcers was not a factor, they appeared to have comparable benefits. However, when the cost of both reinforcers was increased by substantially raising the FR requirement, food was chosen to the near exclusion of fat. If reinforcer efficacy or value reflects the ability of the consequence to maintain substantial amounts of behavior, then sensitivity to changes in the price of the reinforcer may be a more useful measure of reinforcer value than preference. Accordingly, Hursh and Silberberg argued that the steepness of a demand curve provides a useful metric of reinforcer value: Steeply declining demand curves suggest a weak reinforcer with benefits that do not justify the increasing costs of acquiring it. Shallowly declining demand curves reflect substantial expenditure of resources (e.g., effort, time, money) to obtain the reinforcer when its price increases. This intuitive account of reinforcer value requires a way to quantify the steepness of the demand curve. Price elasticity of demand quantifies steepness at a single point on the demand curve. However, the steepness of the demand curve reflects how these point-price elasticities change. Therefore, Hursh and Silberberg proposed an exponential demand equation with a single free parameter to quantify how steeply the demand curve declines (across the entire demand curve) with increases in price.

## QUANTIFYING VALUE FROM DEMAND CURVE DATA

Hursh and Silberberg (2008) argued, and provided considerable empirical data supporting the position, that demand curves may be well fit by an exponential decay function when the logarithm of consumption is plotted as a function of price:

$$\log\ Q = \log\ Q_0 + k\left(e^{-\alpha\left[Q_0 \cdot c\right]} - 1\right). \qquad (1)$$

The independent variable in Equation 1 is cost ($C$), and it is typically measured as the number of responses or units of time spent acquiring each reinforcer. Peak consumption ($\log Q_0$) is obtained empirically by making the reinforcer available at a zero (or minimal) cost. $k$ is a scaling constant that reflects the log-unit range of the consumption data plotted in the demand curve. If $k$ is set to a constant range across reinforcer comparisons, the slope of the demand curve at a given value of $C$ (i.e., the point-price elasticity) is determined by the free parameter, $\alpha$. Thus $\alpha$ quantifies the rate of change in log consumption with increases in $C$.

An important characteristic of Equation 1 is that $\alpha$ is unaffected by the scalar properties of a reinforcer (e.g., magnitude, dose). To understand the importance of this for quantifying the value of a reinforcer, consider the results of an experiment conducted by Hursh et al. (1988). Two groups of rats worked for food in a closed economy. For the small-reinforcer group, one food pellet was earned for each lever press, whereas the other group earned two pellets per press. Under these conditions, both groups consumed a little more than 530 pellets per day. However, because of the difference in reinforcer size, $Q_0$ in the small-reinforcer group was 533 reinforcers, whereas it was 273 in the large-reinforcer group. Obviously, $Q_0$ does not measure reinforcer value; in this case, it reflects the scalar difference in reinforcers across groups. So that estimates of $\alpha$ in Equation 1 are unaffected by the scalar properties of the reinforcer, Equation 1 uses $Q_0$ as a multiplier of $C$ (i.e., $Q_0 \cdot C$). In this way, Equation 1 standardizes price ($Q_0 \cdot C$) so that it reflects the cost of achieving peak consumption of the reinforcer. In the remainder of the Hursh et al. study, pellets were earned at FR values ranging from 1 to 360. The resulting demand curves were well fit by Equation 1 ($R^2 > .98$ in both cases), and because of the scalar invariance property of the equation, it provided a single value of $\alpha$ across groups. Hursh and Silberberg (2008) referred to $\alpha$ as a measure of the essential value of a reinforcer because it provides a single quantitative measure of an organism's defense of consumption in the face of constraint.

[1]We use the term *beneficial* to match the term *benefit* in *cost–benefit ratio;* it should not be read as though reinforcers derive their function from benefits. A more scientifically defensible term would be *consequent*.

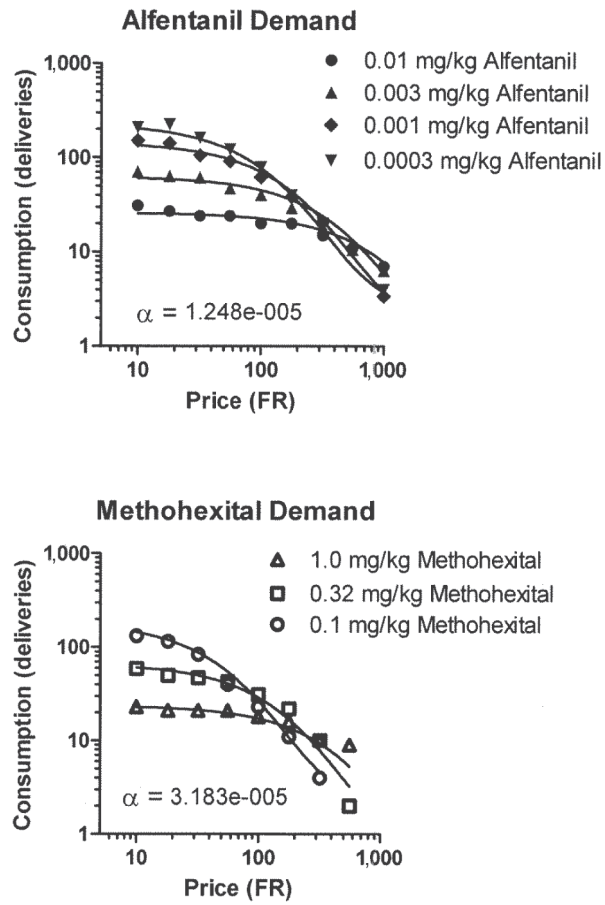
Commodities that are most vociferously defended are the most essential.

Larger values of α reflect steeper demand curves and less essential value, and small α values come from shallow demand curves. Thus, α values are inversely related to value. A perhaps more intuitive measure of essential value, and one that may be derived from α, is $P_{max}$.[2] $P_{max}$ is inversely proportional to α and can be found using the following approximation:[3]

$$P_{max} = \frac{0.65}{\alpha \cdot Q_0 \cdot k^{1.191}}. \quad (2)$$

As noted earlier, $P_{max}$ is the price (in units of $C$) at which the slope of the demand curve (i.e., point-price elasticity) is −1. $P_{max}$ is also the price at which peak responding is achieved; at higher prices, responding declines along the descending limb of the inverted u-shaped response output function. Higher $P_{max}$ values reflect a greater expenditure of resources in defense of consumption.

As an example of how these techniques may be used to compare the value of different reinforcers, we summarize the results of a comparison of two different drug reinforcers (alfentanil, a potent opiate, and methohexital, a short-acting anesthetic) self-administered in different sessions by monkeys (Hursh & Winger, 1995). Figure 8.3 shows the across-subjects average consumption (number of drug deliveries) of each drug at the prices (number of lever presses per injection) shown on the *x*-axis; the demand curves were fit using Equation 1. The first thing to note is that within-drug doses varied by three orders of magnitude. Because Equation 1 accounts for scalar differences by expressing price as the cost of achieving $Q_0$, the α value obtained at every dose of the same drug was the same (see the bottom of Figure 8.3). Because scalar differences in drug potency do not affect α, a direct comparison of the essential value of the different drugs could be made. Although methohexital was reinforcing at unit doses 300 times higher than the lowest dose of alfentanil, its essential value was 2.5 times lower than that of alfentanil (recall the inverse relation




| | *k* | α | Pmax (normalized) | $R^2$ |
|---|---|---|---|---|
| Alfentanil | 1.893 | 1.25E-05 | 244 | 0.98 |
| Methohexital | 1.893 | 3.18E-05 | 96 | 0.96 |

**FIGURE 8.3. Exponential demand curves fit to average consumption of two drugs self-administered by rhesus monkeys. The drugs were alfentanil and methohexital. Parameters of the demand curves and $P_{max}$ values are shown at the bottom of the figure. The α value for methohexital was 2.5 times greater than the value for alfentanil. $P_{max}$ is shown in normalized units of price, which is the result of Equation 2 multiplied by $Q_0$ and divided by 100. The α values are constant across doses of each drug, and the k values were constant for all curves. The global $R^2$ for each drug is also shown. FR = fixed ratio.**

[2]Other potentially useful metrics are consumption at $P_{max}$, which is found by solving Equation 1 with $C = P_{max}$, and $O_{max}$, peak response output, which is found by taking the solution of Equation 1 with $C = P_{max}$ and multiplying this level of consumption by $P_{max}$.

[3]Because $Q_0$ appears twice in the first derivative of Equation 1, there is no closed form solution for $P_{max}$, that is, price at which the first derivative of Equation 1 = −1, and exact $P_{max}$ values can only be found using an iterative solver. However, Equation 2 provides a close approximation within a specified range of values of $k$. The expression approximates $P_{max}$ with a precision that is virtually exact for $k = 5$ and within ±2% for $2 \le k \le 6$, within ±5% for $1.8 \le k \le 8$, and average error of 1.5% for $2 \le k \le 6$.

between α and essential value). These differences were reflected in $P_{max}$ with a larger value for alfentanil. Here, $P_{max}$ is shown in normalized units of price to account for differences in dose that shift $Q_0$.[4]

## VARIABLES AFFECTING VALUE

The term *essential value* may suggest to some readers that the goal is to quantify value as an essential, invariant characteristic of the reinforcer. As any economist who studies consumer demand will tell you, this is not the goal because sensitivity to price manipulations may be affected by several nonprice variables. The word *essential* reflects how necessary the reinforcer is to the organism, and variables that decrease the necessity of obtaining that reinforcer should decrease essential value. One category of these variables is the availability of other reinforcers. Economists have extensively studied interactions between reinforcers that consumers may choose between, and they describe these on a continuum from substitutes to complements. Understanding this continuum will facilitate a discussion of how the availability of other reinforcers affects essential value.

### Availability of Substitutes and Complements

The substitute to complement continuum is illustrated categorically in Figure 8.4. To determine the relation between two reinforcers (A and B), A is made available at a constant price and the price of B is increased. If consumption of A increases with the price of B, then one can say that A substitutes for B. If the opposite manipulation is conducted (price of A is increased and price of B is held constant) and consumption of B increases, then one can say that B also substitutes for A. Perfect substitutes demonstrate this reciprocal relation: If the gas station on the north side of the street increases the price of a gallon of gas, then, all else being equal, consumers will purchase more gas at the south-side station. If next week, the south-side station increases prices, then consumers will head to the north side (see Herrnstein & Loveland, 1975, for similar findings with pigeons). Because the gasoline sold at the two stations, and the food obtained by pecking the two keys, are identical, one reinforcer perfectly substitutes for the other.

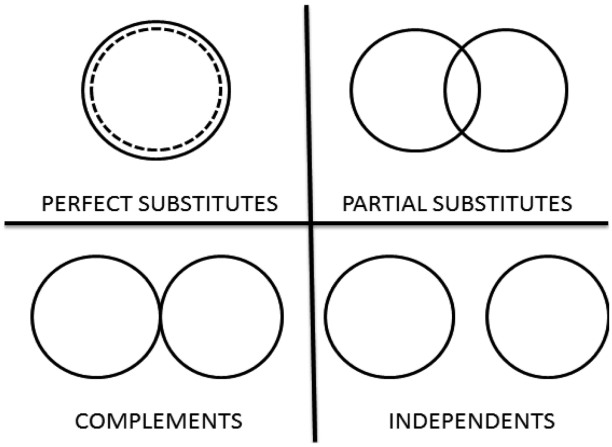



**FIGURE 8.4. Diagram of four hypothetical forms of reinforcer interactions. Perfect substitutes serve an identical function, whereas partial substitutes serve a partial function of the other reinforcer. Complements interact, but in a different way than substitutes. Independent reinforcers do not interact. Based on material from *Reframing Health Behavior Change With Behavioral Economics* (p. 38) by W. K. Bickel & R. E. Vuchinich (Eds.), 2000, Mahwah, NJ: Erlbaum. Copyright 2000 by Lawrence Erlbaum Associates. Adapted with permission.**

Perfect substitutes are arranged to affect the essential value of a reinforcer in two common ways. First, if a perfect substitute is delivered either for free or at a low cost outside of the experimental session, then food earned during the session is not as essential as it would be if the only source of food were that available at the price prevailing during the session. Hursh (1980) termed these arrangements *open economy* and *closed economy*, respectively. An example is illustrated in Figure 8.5. In this study, Hursh (2000) assessed a monkey's demand for food during 12-hour sessions at a range of prices. In one condition, all of the food consumed was earned during the sessions (closed economy). In the open economy condition, the session ended with the initiation of a 60-minute period in which low-cost food was available: Food was delivered after each response (FR 1). The essential value of food in the open economy was less than in the closed economy (α value 2.5 times greater in the open economy than the closed economy), and the monkey's peak response output was reached at a lower price ($P_{max}$)

[4]Normalized $P_{max} = P_{max}\, Q_0/100 \approx 0.0065/(\alpha\, k^{1.191})$

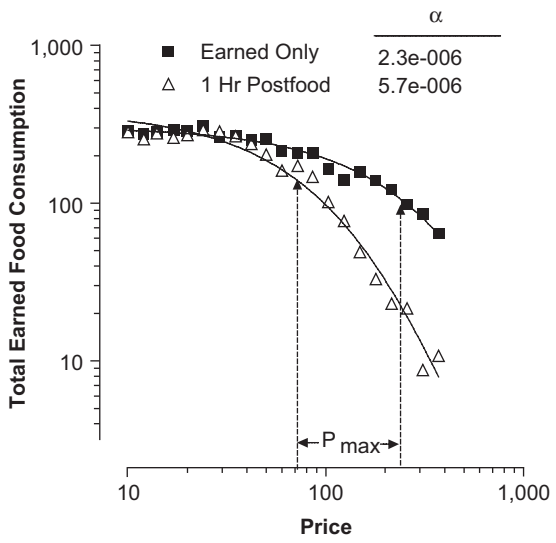



**FIGURE 8.5. Two demand curves produced by a rhesus monkey responding for food during a 12- hour work period, either with no other source of food or with a 1-hour period of fixed-ratio (FR) 1 food reinforcement made available immediately after the work period. Consumption is shown as a function of the FR schedule that ranged from FR 10 to FR 372. Alpha values were derived using Equation 1. Data from Hursh (2000).**

in the open economy, reflecting reduced defense of within-session consumption that is no longer essential to survival. Similar differences have been documented in several studies comparing demand in open and closed economies (Bauman, 1991; Collier, 1983; Collier, Johnson, Hill, & Kaufman, 1986; Foster, Blackman, & Temple, 1997; Greenwald & Steinmiller, 2009; Hall & Lattal, 1990; Hursh, 1978, 1984, 1993; Hursh & Natelson, 1981; Hursh, Raslear, Bauman, & Black, 1989; Hursh et al., 1988; LaFiette & Fantino, 1988, 1989; Lucas, 1981; Raslear, Bauman, Hursh, Shurtleff, & Simmons, 1988; Roane, Call, & Falcomata, 2005; Zeiler, 1999). The difference in spending (i.e., response output) across open and closed economies underlies consumer protection laws that forbid the formation of monopolies. If only one supplier of an essential commodity exists (closed economy), then consumers will consume less and pay more for the commodity, an outcome that unfairly favors the supplier.

The second procedure for arranging perfect substitutes is to make them available concurrently so that the consumer may choose between vendors. Most studies of choice with animals have arranged for the alternative behaviors to provide the same, perfectly substitutable reinforcer, usually food, which yields a specific kind of environment–behavior interaction in which the amount of behavior allocated to each source of reinforcement roughly matches the relative rate of reinforcement received from the source (the matching law; see Volume 1, Chapter 14, this handbook, or Chapter 7, this volume). These studies do not measure total consumption or essential value; however, the response rate and response allocation data are suggestive of the effects on measures of essential value. For example, as noted earlier, responses allocated to obtaining Reinforcer A decline when a perfect substitute, B, is available at a lower price (e.g., Green & Rachlin, 1991). Likewise, periodically providing free access to a perfect substitute will decreases instrumental responding for food (e.g., Rachlin & Baum, 1972). Bickel, Madden, and DeGrandpre (1997) reported that periodically providing free cigarette puffs during a session in which puffs were earned decreased consumption and generally increased price elasticity of demand for earned puffs. Many choices made in the natural economy are between commodities that are not perfect substitutes but fall into one of the other interactions depicted in Figure 8.4.

In their everyday lives, people rarely choose between perfect substitutes. Instead, they choose to allocate their resources between different reinforcers that share some, but not all, characteristics. For example, Kagel et al. (1995) examined rats' consumption of equally priced root beer and Tom Collins mix and found that rats consumed about 3 times as much root beer. In a subsequent condition, the price of root beer was increased, and the price of Tom Collins mix decreased. If the latter functioned as a perfect substitute for the former, then, all else being equal, Tom Collins mix (the lower priced commodity) should have been exclusively consumed. Instead, root beer consumption fell by about 40%, and Tom Collins mix consumption more than tripled. This reveals an important characteristic of imperfect substitutes: The consumer will not trade one unit of A for one unit of B if B only partially substitutes for A. Reinforcer B typically lacks some quality possessed by A. For example, a bus ride

functions as a partial substitute for driving a private vehicle to work. The bus will get you to work on time, but it lacks the comfort of a private vehicle.

The effect of partial substitutes on essential value is illustrated in Figure 8.6. In one condition, humans could obtain doses of methadone (0.4 milligrams per delivery) by pressing a lever under an increasing series of FRs (methadone alone). During a second condition, methadone and a different opiate, hydromorphone (0.15 milligrams per delivery), were concurrently available, but hydromorphone was available at a constant price (FR 32). At the lowest price of methadone (FR 32), very little hydromorphone was consumed. As the price of methadone increased and methadone consumption decreased, consumption of hydromorphone increased, revealing a substitute relation between these two drugs. This is called a *cross-price change* in demand for hydromorphone, because consumption changed in response to the price of another good (discussed in more detail later). Of further note is the change in elasticity of methadone ($\alpha$) when hydromorphone was available as a substitute. Sensitivity to methadone price more than doubled when hydromorphone was available and peak consumption ($Q_0$) was reduced by a third (80 vs. 120). Similar findings

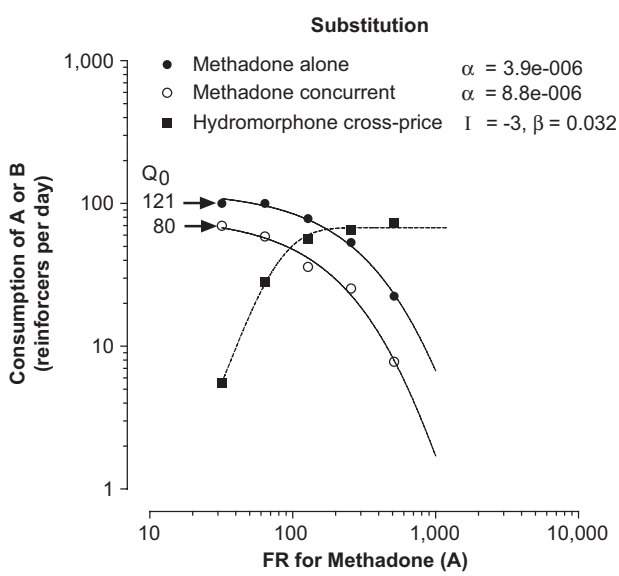



**FIGURE 8.6. Mean daily consumption by human subjects of methadone and hydromorphone as a function of the price (fixed-ratio [FR] schedule) of methadone, in log-log coordinates. Data from Spiga (2006).**

have been reported when the partial substitute was a nondrug reinforcer (Greenwald & Steinmiller, 2009) and when both the target and partial substitutes were nondrug reinforcers (Tustin, 1994).

A final reinforcer interaction is a complementary relation. Reinforcers are described as complements when they tend to be consumed at a constant ratio (e.g., one tortilla chip to 5 grams guacamole, one left shoe to one right shoe). A complementary relation between reinforcers is demonstrated if the price of one reinforcer increases (e.g., the price of guacamole doubles) and consumption of both reinforcers (chips and guacamole) decreases, despite no increase in the price of chips. Such a decrease reveals the tendency of the two commodities to be consumed in a constant ratio.

A complementary relation is illustrated in Figure 8.7. In this study conducted by Spiga, Wilson, and Martinetti (2011), humans smoked cigarettes and drank ethanol-containing beverages available at a range of prices. In the left panel, cigarette consumption was measured across a wide range of cigarettes prices (FR 10–512). In one condition, cigarettes were the only commodity available for purchase (closed circles), whereas in a separate condition cigarettes (open circles) could be purchased at this range of prices, and ethanol (closed diamonds) was concurrently available at a fixed price (FR 32). Two interesting effects were observed. First, when cigarette prices increased, consumption of cigarettes and ethanol decreased. The latter decrease, despite no change in the price of ethanol, reveals a complementary relation between cigarettes and ethanol. Second, making a complement (ethanol) available increased cigarette consumption and increased the essential value of cigarettes (i.e., lower value of $\alpha$). A similar relation is shown in the right panel of Figure 7. When the price of ethanol increased, ethanol and cigarette consumption both declined, and the essential value of ethanol increased when cigarettes were concurrently available.

Reinforcer interactions from substitutes to complements may be quantified using cross-price elasticity of demand—the slope of the demand function relating consumption of a fixed-price reinforcer to the changes in price of an alternative commodity. As noted earlier, if this function has a positive slope,

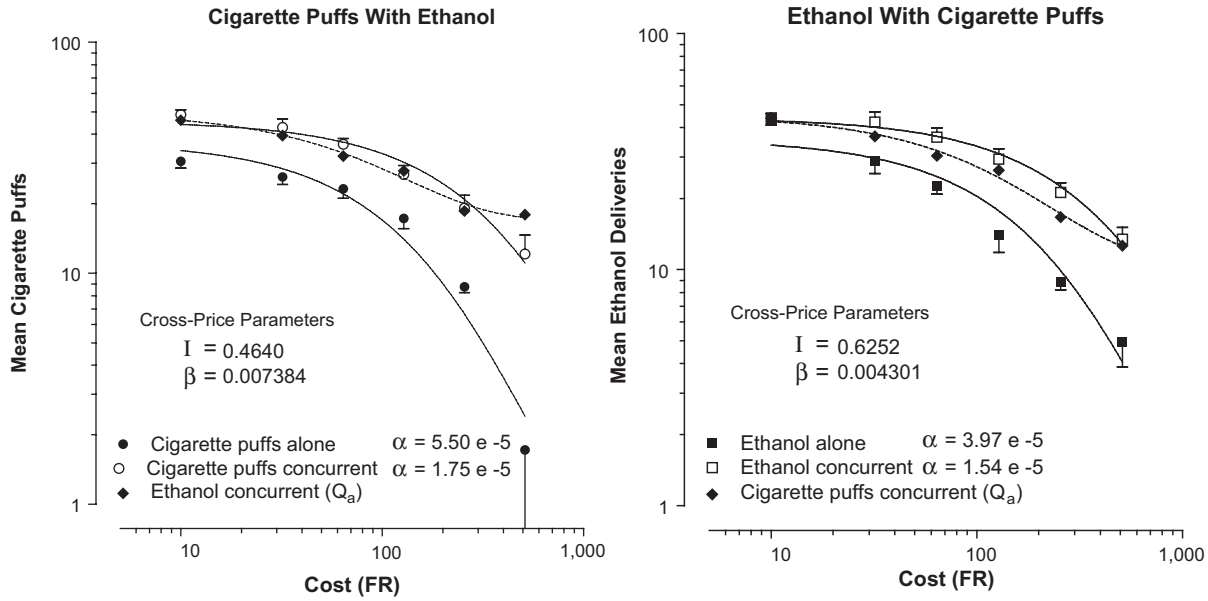



**FIGURE 8.7. For human subjects, consumption of cigarette puffs or ethanol drinks. Left: The price of cigarettes was manipulated with and without ethanol concurrently available at a fixed price. Right: The price of ethanol was changed with and without cigarettes concurrently available at a fixed price. FR = fixed ratio.**

then the second commodity is a substitute for the first (Figure 8.6); if the slope is negative, then the second commodity is a complement of the first (Figure 8.7); if the slope is zero, they are independent (i.e., no interaction between the reinforcers).

An extension of exponential demand was used to fit the cross-price demand curves in Figure 8.6 for hydromorpone (substitute for methadone) and in Figure 8.7 for ethanol and cigarettes (complements to each other):

$$Q = \log\left(Q_{\text{alone}}\right) + Ie^{-\beta \cdot C}, \qquad (3)$$

where $Q_{\text{alone}}$ is peak consumption of the fixed-price reinforcer at the lowest price of the other reinforcer, $I$ is the interaction constant, $\beta$ is sensitivity of consumption of the fixed-price reinforcer to changes in the price of the other reinforcer, and C is the cost of the variable-price reinforcer. In Figure 8.6, the interaction term $I$ was negative (−3), indicating a reciprocal or substitute relation between consumptions of the two commodities; in Figure 8.7, the interaction terms $I$ were positive (0.5 for ethanol and 0.6 for cigarettes), indicating a parallel or complementary relation between consumptions of ethanol and cigarettes.[5]

To summarize, essential value may be dramatically affected by the availability of alternative reinforcers. When substitutes are available, the essential value of a reinforcer declines relative to when no other source of reinforcement is available. Low-priced concurrently available perfect substitutes produce large decreases in essential value, with imperfect substitutes (Kagel et al., 1995) and delayed alternatives (e.g., Roane et al., 2005) producing more modest declines in essential value. At the other end of the continuum, concurrently available complements increase the essential value of a reinforcer. These reinforcer interactions are not traditionally incorporated into prominent models of decision making such as Herrnstein's (1970) matching law, although interested readers should see Green and Rachlin (1991) or Herrnstein and Prelec (1991).

## Essential Value and Cost Variables

An untested assumption of the exponential demand equation is that estimates of essential value are general to other cost manipulations. That is, Equation 1

[5]If the prices of both Commodity B and Commodity A are changing, then Equation 3 can be expanded by replacing the $\log(Q_{\text{alone}})$ term for Commodity B consumption at a fixed own-price with Equation 1 that specifies how consumption of Commodity B varies with a variable own-price. This expanded form provides an economic foundation for determining choice ratios as the ratio of several such expanded demand equations, a topic beyond the scope of this chapter.

does not specify how costs are operationalized, and therefore, the assumption is that measures of essential value such as α will be unaffected by the variety of ways in which costs may be arranged. To date, tests of Equation 1 have been limited to studies in which costs are operationalized as FR values.

As an initial test of the generality of essential value estimates, we used Equation 1 to fit the demand curves shown in Figure 8.8. In this closed economy study conducted by Madden et al. (2005), pigeons pecked a key to obtained three 45-milligram food pellet reinforcers in two separate conditions. In one condition, the cost of food was set by an FR schedule, whereas in the other condition, costs were programmed according to a random-ratio (RR) schedule (each response has a constant probability of leading to reinforcer). Because the reinforcer was identical across conditions, the essential value of food should be unaffected by how cost was operationalized. Despite the effort costs being identical across conditions (e.g., 48 pecks per reinforcer or an average of 48 pecks per reinforcer), demand for food proved to be substantially more elastic when the FR schedule controlled the delivery of food. This difference is reflected in the α values shown in Figure 8.8.

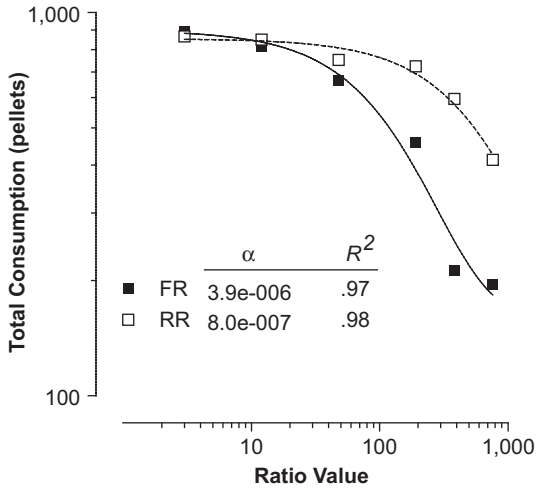



**FIGURE 8.8. Pigeons' averaged food consumption under fixed-ratio (FR) and random-ratio (RR) schedules. The $R^2$ values suggest the data are well fit by Equation 1, but the different α values reveal that essential value is affected by schedule of reinforcement type. Data from Madden et al. (2005).**

These data are consistent with Hursh and Silberberg's (2008) position that the value of a reinforcer is determined not only by its benefits but also by its costs. However, Equation 1 does not incorporate a parameter for how costs are operationalized. A general solution to this problem may be scalar transformations of different cost manipulations (e.g., expressing RR values as harmonic rather than arithmetic means; see Killeen, 1968). Such transformations may prove useful if one's goal is to precisely quantify the essential value of a reinforcer across many different cost manipulations. However, if one's goal is merely to rank order the essential value of a variety of reinforcers, then Equation 1 may prove adequate. Evaluating this possibility will require experiments in which several different reinforcers are rank ordered on the basis of their essential values obtained under one cost manipulation (e.g., delay to reinforcer delivery) and then these rankings are redetermined under a different cost manipulation (e.g., effort expended). Such a study would evaluate the ordinal generalizability of essential value.

## DISCOUNTING THE VALUE OF DELAYED OUTCOMES

A few studies have examined the effects of reinforcer delay as a cost factor affecting consumer demand (e.g., Bauman, 1991; Tsunematsu, 2000). Those studies that have been conducted have reported that when delay costs are increased, demand for the reinforcer follows a positively decelerating demand function comparable with those in the preceding figures in this chapter. To our knowledge, no studies have yet used Equation 1 to estimate reinforcer value when delay is the cost variable. Instead, the bulk of the behavioral economic research on the effects of delay on reinforcer value has been conducted in the delay discounting literature. These studies have used psychophysical procedures to estimate the value of delayed reinforcers. One widely used and illustrative procedure asks human or animal subjects to make repeated choices between a smaller–sooner reinforcer (SSR) and a larger–later reinforcer (LLR). Depending on the choice made on Trial *x,* the amount of the SSR arranged on Trial $x + 1$ is either increased (the subject chose the LLR) or

decreased (the subject chose the SSR). This choice-dependent adjustment process is repeated until the subject is indifferent between the reinforcers. At this indifference point, the value of the LLR is given by the amount of the SSR. This process is repeated at a range of delays to delivery of the LLR, and the resulting indifference points are plotted as a function of their delay. The resulting delay-discounting function is shown as the solid curve in the top panel of Figure 8.9. This finding is remarkably consistent across species and reinforcer types (see Madden & Bickel, 2010, for a review).

Across species, the hyperbolic discounting equation (Mazur, 1987) well describes steady-state choices:

$$V = \frac{A}{(1+kD)}. \tag{4}$$

In Equation 4, $A$ is the amount of the LLR, $D$ is the delay to its delivery, and $k$ is a free parameter that varies with the steepness of the discounting

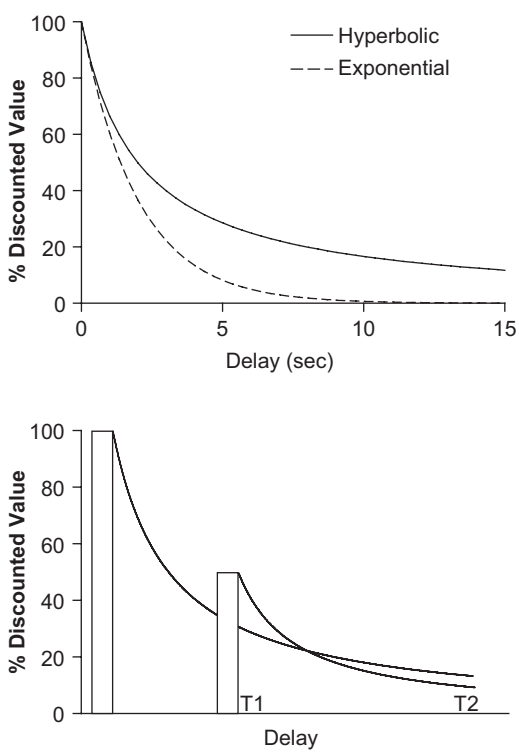



**FIGURE 8.9. Top: Illustrative hyperbolic and exponential delay discounting functions. Bottom: Irrational preference reversals predicted by the hyperbolic shape of human and nonhuman discounting functions. T1 = Time 1; T2 = Time 2.**

function. When humans make prospect choices between immediate and delayed rewards, their pattern of choices conforms to the same hyperbola describing animal choices involving real delays and real reinforcers (e.g., Green, Fry, & Myerson, 1994; Kirby, 1997; Rachlin, Raineri, & Cross, 1991; although see Green & Myerson, 2004, for evidence that for humans the curve may deviate slightly from a strict hyperbola).

This finding has been of great interest to behavioral economists because the hyperbolic shape of the delay discounting curve is not predicted by normative economic theory. The latter holds that the value of a delayed outcome should decline exponentially, as shown by the dashed curve in the top panel of Figure 8.9 (e.g., Samuelson, 1937). An exponential decay function is the outcome of devaluing a reinforcer at a constant rate over time. For example, in Figure 8.9 the delayed reward loses 39% of its value when delayed by 1 second (discounted value = 61%). At a 2-second delay, the reward is discounted by an additional 39% (discounted value is 37% = 61 − [61 × 0.39]), and so on.

Given the considerable body of empirical evidence that human and nonhuman choice reflects a hyperbolic rather than an exponential discounting process, several behavioral economists have hypothesized that hyperbolic discounting may be the product of two exponential discounting processes (e.g., McClure, Laibson, Lowenstein, & Cohen, 2004). One process is controlled by limbic brain structures that discount delayed rewards according to a steep exponential decay function when an immediate reward is available. The other process is controlled by frontal cortex structures and discounts rewards in the upper range of delays according to a more shallow exponential curve. The temporal proximity of the reward is presumed to control the degree to which these two processes are engaged, with more immediate rewards uniquely able to control limbic function. This model of discounting has not been universally embraced (e.g., Ainslie, 2010), and empirical challenges exist (e.g., Peters, 2011). However, as discussed later in the chapter, the model has inspired a new executive function training approach to improving delay tolerance in drug-using populations (Bickel, Yi, Landes, Hill, & Baxter, 2011).

Regardless of whether hyperbolic discounting ultimately proves to be fundamental or the product of two exponential decay processes, hyperbolic delay discounting may help to make sense of some forms of irrational behavior that make little sense from a normative economic perspective. For example, exponential delay discounting predicts that organisms should be rational decision makers in the sense that choice should not waver over time. A rational cigarette smoker who decides to quit smoking on Monday would not waver from this decision on Tuesday, not even when faced with an immediate temptation such as the offer of a free cigarette. Likewise, other people, having committed to pursuing a healthy diet, exercise, and debt repayment would walk the straight and narrow until their goal was achieved. People's everyday experience, however, tells them that they are not rational decision makers.

Choice inconsistencies such as drug relapse, breaking a diet, and incurring more debt are predicted by the shape of the hyperbolic discounting function. To illustrate, the bottom panel of Figure 8.9 shows two vertical bars corresponding to the LLR and SSR. When choices are made at Time 1, the SSR (e.g., a high-calorie, high-fat hamburger) is immediately available, whereas the LLR is delayed (e.g., staying with your diet and later experiencing health benefits, weight loss, etc.). At Time 2, both reinforcers are delayed, with the difference in delivery time at Time 2 being the same as at Time 1. Also shown are two hyperbolic discounting curves, both using the same rate of discounting (i.e., *k* value). Assuming that choice favors the reinforcer with the greater discounted value (i.e., the higher of the two curves) at Time 2, the individual chooses the LLR. Thus, after an overindulgent meal, one resolves to eat better next time. Unfortunately, something dreadful happens as the next meal gets closer—one travels from Time 2 to Time 1. Along this path, the discounted values of the reinforcers are switching positions as an immediate temptation (SSR) gets nearer. At Time 1, with menu in hand, the value of the hamburger now outweighs the delayed benefits of pursuing a healthy diet. Although this irrational choice is not predicted by the economist's exponential discounting process (exponential discounting curves do not cross), it is by hyperbolic delay discounting.

The interspecies generality of hyperbolic delay discounting would appear to suggest that people are doomed by their phylogenetic heritage to make irrational intertemporal choices. According to the ecological rationality hypothesis, choosing immediate over delayed reinforcers may have offered organisms a selective advantage in a natural environment filled with predators, competition, unpredictable food supplies, and scarce mating opportunities (e.g., Stevens & Stephens, 2010). These tendencies, well honed by natural selection, are not well suited to the unnatural context in which consumer choices are frequently made: A context in which consumables never imagined by people's foraging ancestors are now readily available if they are just willing to sacrifice their long-term health or wealth to consume them.

Individuals who very steeply discount the value of delayed rewards would be expected to be most susceptible to the draw of immediate temptations. A steeply discounted delayed reward retains almost none of its value and therefore cannot compete with an immediate reward. Conversely, those whose choices produce a shallow discounting curve would be expected to eschew SSR temptations because they cannot compete with the nominally discounted value of the LLR.

Consistent with this prediction, a substantial body of research conducted over the past decade or so has revealed that individuals diagnosed with a substance use disorder (MacKillop et al., 2011; Yi, Mitchell, & Bickel, 2010), pathological gambling (Petry & Madden, 2010), or obesity (Davis, Patte, Curtis, & Reid, 2010; Rasmussen, Lawyer, & Reilly, 2010) more steeply discount delayed rewards. Data suggesting that delay discounting may play a role in the initiation, continuation, or relapse to one of these addictions come from two sources. First, animal experiments in which delay discounting is assessed first and rats are then given the opportunity to self-administer cocaine have suggested that steep delay discounting of food rewards predicts the acquisition of sustained cocaine self-administration (see review by Carroll, Anker, Mach, Newman, & Perry, 2010). The same has not been observed of nicotine self-administration (Diergaarde et al., 2008), perhaps owing to the substantial training necessary to produce nicotine self-administration in

rats. However, Diergaarde et al. (2008) found that when the price of nicotine was increased by increasing the FR requirement, demand for nicotine proved to be more inelastic among the rats that most steeply discounted delayed food rewards (i.e., the essential value of nicotine was higher for the impulsive rats). These rats were also more likely to press the nicotine lever after an extinction phase when nicotine reinforcer cues were presented.

Second, human studies have suggested that the steepness of the delay discounting curve is predictive of (a) the initiation and escalation of cigarette smoking (Audrain-McGovern et al., 2009), (b) success in substance abuse treatment (e.g., MacKillop & Kahler, 2009), and (c) relapse after treatment (Yoon et al., 2007). Thus, steep delay discounting is correlated with the propensity to engage in a variety of drug-related activities. Stronger statements of the role that steep delay discounting may play in drug taking and other addictive behavior must await the result of studies that experimentally manipulate the steepness of the discounting curve. Assuming that discounting is not a trait (Odum, 2011), an experimental manipulation of delay discounting will allow us to determine whether steep discounting is causally related to addiction.

The latter experimental approach characterizes studies evaluating the effects of acute and chronic drug exposure on delay discounting. Acute dosing in animals has produced a large but very mixed literature, with some studies showing an effect in one direction and others showing the opposite or no effect. When the effects of a drug are consistent (e.g., nicotine), the number of studies conducted to date is very small (see review by de Wit & Mitchell, 2010). Among humans, acute doses have produced almost no effect on delay discounting (de Wit & Mitchell, 2010), which may be a product of using hypothetical rewards and delays (see Reynolds, Richards, & de Wit, 2006). By contrast, chronic exposure to cocaine, either provided by the experimenter or self-administered, appears to increase the degree to which delayed rewards are discounted (see review by Mendez et al., 2010). This does not appear to be true of all drugs of abuse, because chronic amphetamine exposure produces no effect on delay discounting (e.g., Floresco & Whelan, 2009).

In sum, the direction-of-causation arrow is not consistently pointing in a single direction. Individuals who steeply discount the value of delayed rewards may be more likely to initiate and escalate cocaine use, whereas neuroadaptations to chronic cocaine would appear to produce greater intolerance of delays (i.e., steeper delay discounting curves; Setlow, Mendez, Mitchell, & Simon, 2009). Considerably more research is needed to explore the generality of these findings across drugs, species, and procedures and to determine whether drug self-administration is affected by experimental manipulations of delayed reward discounting.

## TRANSLATING BEHAVIORAL ECONOMICS

The translational utility of these concepts, methods, and analyses are many. For example, quantifying the value of drug reinforcers under identical contextual circumstances (e.g., monkeys self-administering drugs at a range of FR requirements in a closed economy) may prove useful in evaluating the abuse liability of newly developed analgesic medications; those that produce high $P_{max}$ values would be released with warning labels and instructions to physicians about the abuse potential of prescribing the drug. As noted earlier, the extent to which these $P_{max}$ values, or perhaps the rank ordering of these values, prove to be applicable to a wide variety of cost manipulations is an area for future research. In this section, we consider a few of the translational directions that have begun to be explored in behavioral economics and those that may show promise in future research. Much of this translational research (and research potential) falls under the rubric of addictions, but a handful of applied behavior analysts have begun to profitably use behavioral economic concepts to suggest new interventions in the treatment of severe problem behavior in individuals with intellectual and developmental disabilities. We consider these translations in turn.

### Measuring Addiction and Treatment Efficacy

Several economic theories have been forwarded to explain the development of an addiction—an increasingly strong tendency to seek and consume a

specific commodity (e.g., Becker & Murphy, 1988). The present application of the demand law offers a systematic, hypothesis-free means by which to describe the neurobehavioral longitudinal changes that are described as addition. Such measures may prove useful in informing present and future theorizing about the origins and progression of addiction.

For example, a growing literature has indicated that for some commodities, extended exposure to the reinforcing properties of that commodity leads to progressive changes in demand (see escalation, e.g., Ahmed & Koob, 1998). In a recent experiment with rodents as subjects (Christensen, Silberberg, Hursh, Huntsberry, & Riley, 2008), demand curves for infusions of cocaine were determined after a brief familiarization with the drug and then after a 2-week history of infusions. Figure 8.10 illustrates the effect of the extended history of consuming cocaine. So as to focus on changes in elasticity, we used an exponential demand equation that sets $Q_0$ of both demand curves to 100% (see Hursh & Winger, 1995). The 2-week history of self-administering cocaine rendered drug demand more inelastic when

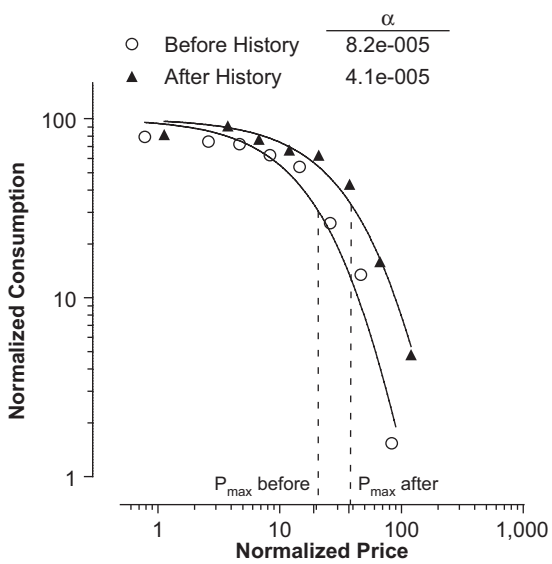



**FIGURE 8.10. For the mean of a group of rodents, consumption of cocaine infusions as a function of increasing fixed-ratio schedules before and after a 2-week history of exposure to cocaine, in log–log coordinates. The shift in $P_{max}$ is shown as the two vertical dashed lines. Data from Christensen, Silberberg, Hursh, Huntsberry, and Riley (2008).**

compared with postacquisition demand (50% reduction in α; $P_{max}$ increase from 19 to 37; for similar findings, see Wade-Galuska, Galuska, & Winger, 2011). There may be utility in conceptualizing addiction as a longitudinal experience-dependent shift in the essential value of a reinforcer, pursued to the relative exclusion of other commodities—a process that may be quantified using the procedures outlined earlier.

Building on these assumptions, some researchers have begun to ask whether characteristics of demand curves are correlated with intensity of drug dependence, affected by relapse cues, and whether these characteristics have predictive utility in determining responsivity to treatment, relapse, and so forth. Several first steps have been taken in this emerging literature. Murphy, MacKillop, Tidey, Brazil, and Colby (2011), for example, used a simulated cigarette purchase task to quantify elasticity of demand for cigarettes among adolescent smokers. The adolescents were asked to report how many cigarettes they would purchase per day if cigarette prices varied across a wide range. So as to quantify demand in a simulated closed economy, participants were asked to imagine that no other source of cheaper cigarettes was available. Equation 1 provided good fits of individual participants' simulated demand functions, with $O_{max}$ (i.e., peak spending) most consistently correlated with participants' level of nicotine dependence. A very similar methodology was used by Madden and Kalman (2010), who reported that therapy-related changes in essential value of cigarettes (α) were predictive of smoking cessation at 2-month follow-up. The simulated purchase task also proved useful in quantifying increases in the essential value of alcohol when heavy drinkers were exposed to the smell of their preferred alcoholic beverage (MacKillop et al., 2010). Procedures such as these hold the promise of integrating more ambiguously defined concepts like "craving" into a quantifiable behavioral economic model of factors affecting drug use and relapse.

A second translational application of the demand curve procedures outlined earlier is in evaluating the efficacy and mechanisms of action of medications designed to reduce drug use. One category of medications, agonists, has been discussed briefly in

the context of Figure 8.6, and we expand on it here. Agonists are drugs that at least partially substitute for the drug of abuse. For example, methadone is an imperfect substitute for heroin; it is an opiate agonist and has many of the psychoactive properties of heroin and morphine. Methadone is explicitly formulated so that an oral dose will prevent opiate withdrawal but will not produce a pronounced euphoria or high. Given this imperfect substitute interaction, it is not surprising that even when heroin is considerably more expensive than methadone, some heroin is still purchased from illicit sources (see Stitzer, Grabowski, & Henningfield, 1984). In addition, heroin is often consumed socially, and these social events appear to serve as complements to the primary reinforcing consequences of the drug. To the extent that methadone must be consumed in a clinical, nonsocial environment, its value in a no-complement context will be diminished in the same way that the value of cigarettes was diminished when its complement, ethanol, was not available, as shown in the left panel of Figure 8.7 (see Hunt, Lipton, Goldsmith, & Strug, 1984).

Figure 8.11 illustrates how the efficacy of an opioid agonist medication, in this case methadone, may be usefully quantified by measuring its effect on $Q_0$, $\alpha$, or other components of a drug demand curve. A methadone-maintained participant could press a button on a FR 10, 32, 64, 128, 256, or 512 to earn 0.40 milligrams per delivery of methadone, with consumption capped at 40 milligrams (half of their daily methadone maintenance dose). Sessions were conducted between 9:00 and 10:30 a.m., and the unconsumed dose from the session and the remaining portion were provided at either 11:00 a.m. (30 minutes postsession), 2:30 p.m. (4 hours postsession), or 4:30 p.m. (6 hours postsession). Demand for methadone was most elastic when a free source of methadone was available 30 minutes later and was increasingly inelastic as the delay to this substitute increased.

A second class of medications, antagonists, seeks to decrease the reinforcing value of the illicit drug. An antagonist medication binds to the neurochemical receptor and blocks the action of the illicit drug without itself producing a psychoactive effect (see Volume 1, Chapter 23, this handbook). A common

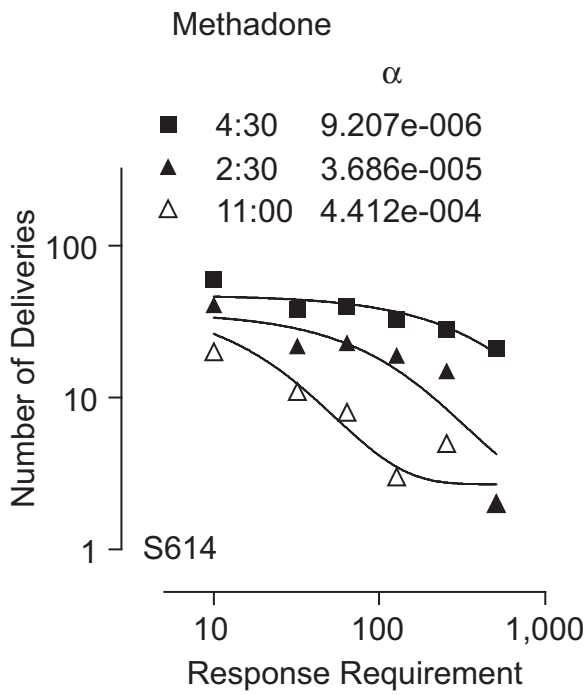



**FIGURE 8.11. Consumption of methadone assessed in a human subject under increasing fixed-ratio schedules in the morning at 9:00 a.m. Additional methadone was available later for free, and the delay to the additional methadone varied from 11:00 a.m. (open triangle) to 2:30 p.m. (closed triangle) to 4:30 p.m. (closed square). The sensitivity to price ($\alpha$) is shown in the legend and decreased with increases in time to the additional methadone. Data from Spiga (2006).**

antagonist for opiate drugs is naltrexone or naloxone; it is used in emergency rooms to rapidly block the action of opiates in patients who have taken an overdose. As a therapy, the antagonist partially or completely blocks the action of the target drug and presumably would reduce demand.

This presumption was tested in a study reported by Harrigan and Downs (1978). Monkeys worked for morphine under a series of increasing unit prices, arranged by decreasing the morphine dose per reinforcer. Morphine self-administration was studied either alone or when combined with two doses of continuous naltrexone infusions. As seen in Figure 8.12, at the lowest common unit price, naltrexone dose dependently increased consumption of morphine. However, when the price of morphine was increased, naltrexone produced dose-dependent larger decreases in demand for morphine. This apparently complicated effect of naltrexone can be

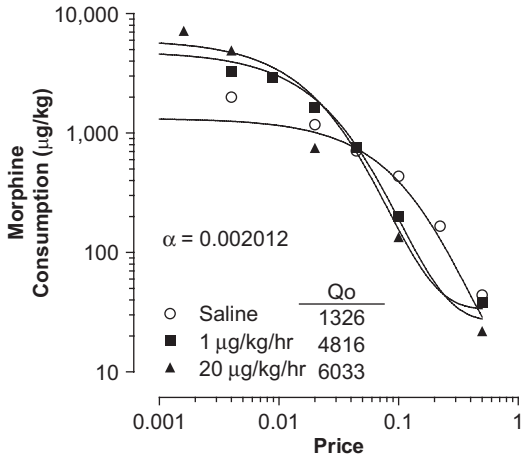



**FIGURE 8.12. Effects of two doses of naltrexone on morphine consumption across a range of morphine prices. The value of α was not significantly different across conditions, but $Q_0$ increased across conditions. Data from Harrigan and Downs (1978).**

resolved by examining the exponential demand curves for morphine alone (saline) and in combination with naltrexone shown in Figure 8.12. The dose-dependent increase in morphine consumption at the lowest common unit price is reflected in the upward shift in $Q_0$. However, naltrexone dose did not affect α (the common value of α is shown in the figure), suggesting that naltrexone did not change the essential value of morphine, it simply lowered the potency of each morphine infusion and raised the effective price of the drug.

As should be clear from examining Figure 8.12, and to the extent that these data are generally characteristic of antagonists, the utility of an antagonist medication depends on the prevailing price of the illicit drug and the price-increasing effect of the medication. When little constraint is placed on acquisition of the illicit drug, drug consumption increases (so as to overwhelm the effect of the antagonist). Such an increase raises at least three problems. First, some of the drug-seeking activity associated with illicit drug purchases involves illegal acts. Second, greater drug consumption translates to larger profits for drug dealers, a situation that may help to recruit more people to jobs in the illicit drug trade. Third, greater consumption of intravenous drugs may increase the use of dirty needles and the risk of needle-transmitted diseases such as HIV/AIDS. For an antagonist medication to produce a net benefit to the illicit drug user and society, the postantagonist price must shift consumption to the elastic portion of the demand curve. There drug consumption and drug-seeking activities both decline.

Assuming that an antagonist medication could produce such a price shift, it raises the challenge of inducing users to voluntarily administer a medication that increases the functional cost of their preferred drug. This might be feasible on a limited scale with court-ordered depot injections of time-released antagonists, but other, less coercive strategies might prove more acceptable. Some antagonist medications produce desirable effects that may increase their acceptability. For example, bupropion is a nicotine receptor antagonist with atypical antidepressant effects (e.g., Dwoskin, Rauhut, King-Pospisil, & Bardo, 2006; Miller, Sumithran & Dwoskin, 2002). In a recent study of the effects of bupropion on simulated demand for cigarettes, Madden and Kalman (2010) reported no change in either $Q_0$ or the essential value of cigarettes after 1 week of bupropion use. This outcome suggests that the mechanism by which bupropion increases smoking cessation is unrelated to changes in the essential value of nicotine as a reinforcer. These studies have demonstrated the potential utility of quantifying the effects of a variety of medication classes on peak consumption and reinforcer value.

## Economic Concepts for the Treatment of Addiction

A third area of translational potential is in treatments for addictive behavior. The difference between inpatient and outpatient treatment for addictive behavior, for example, is an obvious parallel to the distinction between closed and open economies, respectively. In the inpatient setting, the benefits of drug abstinence are "consumed" in a monopolistic setting—no substitute drug reinforcers are available to compete in the inpatient marketplace. When the economy is opened after a person is released from inpatient drug detoxification, drug-abstinence reinforcers must compete with drug reinforcers, a competition that often leads to drug relapse (Wikler, 1977). It is safe to say that detoxification does not cure addiction. This may in part be

due to long-lasting Pavlovian conditioning: Cues in the client's everyday environment that elicit conditioned drug effects (craving) appear to increase the essential value of the drug reinforcer (MacKillop et al., 2010; see Podlesnik & Shahan, 2010, for a complementary account). Detoxification presumably does not affect the essential value of the drug reinforcer, so when drug cues are encountered, drug-seeking behavior is easily reinstated.

Beyond the contribution of drug cues to reinstate behavior maintained by the essential value of illicit drugs, relapse is an important (if not fundamental) reflection of the economic conditions that skew preference toward the illicit commodity. Consider the simple price difference between illicit drugs and nondrug reinforcers. In terms of a cost–benefit ratio, for those using drugs regularly, drugs are typically available at a lower price than nondrug reinforcers. For example, the heroin-dependent individual meets his or her life's goal every day when another bag of heroin is obtained and the drug is injected. The benefits of drug consumption (e.g., euphoria and escape from opiate withdrawal) are enormous relative to the procurement costs of obtaining a dose of heroin (a cost that may be met in a single day with a modicum of effort). Once obtained, the benefits of the injected drug are immediate (undiscounted) and may be accompanied by complementary social reinforcers. By comparison, the costs of a nondrug reinforcer that could compete with the benefits of drug use are much higher and substantially delayed. Acquiring the skills necessary to obtain a job that yields a salary enabling the purchase of goods and services with comparable benefits is years away, as are the benefits of beginning the hard work of repairing or replacing a dysfunctional social network.

Given this imbalance in the price of drug and nondrug reinforcers, a sustained pattern of drug use should surprise no one because to choose to walk the path of abstinence requires a substantial and sustained decrease in the summed value of reinforcers obtained per day (see Herrnstein & Prelec, 1992). That is, one must give up drug reinforcers and contact with drug-using friends and must live for some time without effective substitutes. Individuals addicted to a variety of drugs discount the value of these delayed substitutes more than do comparable individuals with no history of addiction (Yi et al., 2010); thus, these delayed imperfect substitutes cannot compete with the immediate undiscounted value of drug reinforcers. Given this imbalance, it is not surprising that drug users tend to seek drug treatment when they hit rock bottom (e.g., Cunningham, Sobell, Sobell, & Gaskin, 1994); that is, when the price of continuing to use drugs is drastically increased (e.g., loss of drug supply, loss of health, significantly deteriorated social relationships). At this time, treatment seeking represents an increase (or at least a sideways step) in the summed value of reinforcers obtained per day.

Outpatient treatment is a necessary step in the treatment or rehabilitation process; successful progress has been realized by recognizing that such treatment occurs in an open economy in which the benefits of treatment are economic goods evaluated in a competitive market. This is true of a range of outpatient programs beyond those for drug and alcohol abuse (e.g., for obesity). Innovations that increase the immediate benefits and reduce the proximal costs of therapy will serve to swing more clients toward treatment seeking and compliance with the outpatient protocol.

One approach to accomplishing this is to consider the effects of substitutes and complements on demand for the addictive good. As already discussed, making available a low-price substitute will decrease demand for a reinforcer. Carroll and Rodefer (1993) demonstrated this in the lab when monkeys' consumption of PCP decreased (larger values of $\alpha$ and smaller values of $P_{max}$) when a sweet saccharin solution was introduced to the drug self-administration sessions. This substitution effect was more prominent in a separate study when the saccharin solution was made available while rats were initiating cocaine use (Carroll & Lac, 1993). Nonetheless, these substitute effects rarely produced drug abstinence; especially among those animals already consuming drugs on a regular basis (e.g., Comer, Hunt, & Carroll, 1994). One reason is that a saccharin solution is not a perfect substitute for the drug reinforcer; if it were, the subject would exclusively prefer whichever reinforcer was available at a lower price (Herrnstein & Loveland, 1975). A second

reason that abstinence was not achieved is that the contingencies were such that the nondrug reinforcer was available even if the subject was consuming the drug. This is analogous to opening a gymnasium at night to deter drug use and then allowing intoxicated youths to enter the gym.

Achieving abstinence requires that access to the substitute be contingent on drug abstinence (Higgins, 1999). This substitute reinforcer strategy has been successfully used in contingency management of substance abuse (see Chapter 19, this volume). Here, drug abstinence is reinforced with escalating-magnitude tangible rewards designed to partially substitute for the drug of abuse. As abstinence continues, the magnitude of the tangible reward increases, which increases its ability to function as an effective substitute for drugs that may increase in value with physical and psychological withdrawal (Roll & Higgins, 2000). Thus, unlike the animals self-administering drugs in the Comer et al. (1994) study, if a contingency management patient relapses to drug use the tangible reward is not presented, and the patient pays an opportunity cost when the reward magnitude is reset to the initial value.

The consideration of complementary relations between drug and nondrug reinforcers has been limited in the treatment of substance use disorders. Thus, a novel behavioral economic approach to reducing a problem behavior is to search for reinforcers that complement the reinforcer maintaining the problem behavior. If consumption of the latter may be constrained, then consumption of the former will be reduced.

**Polydrug abuse.** Understanding the substitute-to-complement continuum and how these reinforcer interactions affect demand may help to understand polydrug abuse (see Petry & Bickel, 1998). *Polydrug abuse* is the concurrent or sequential consumption of more than one drug of abuse. It is frequently observed in the clinical population and has been identified as a distinct and common pattern of drug use (Chan, 1991; Petry, 2001). According to the economics of consumer choice, the drug user may be thought of as a consumer making choices in an illicit market offering multiple drugs at competing prices. The level of consumption of a single drug is strictly determined not by its own utility and market price but also by the utility and price of available alternatives. Changes in patterns of abuse can only be understood if this context of competing goods is understood.

The administration of clinically prescribed medications, such as methadone, adds another dimension to what, in many cases, is already a complicated picture of multiple drug use. The result of such medications and compliance with medication schedules will depend, in part, on the various elasticities of demand in the entire polydrug marketplace. Ironically, interventions that inhibit reinforcement by one drug (e.g., antagonists) and reduce demand (e.g., price increases) may, at the same time, increase consumption of other drugs that serve as substitutes. Other drugs may also serve a complementary function such that the essential value of Drug A is increased by the availability of a low-priced source of Drug B. Figure 8.13 illustrates these effects in human subjects (Spiga, 2006). In the left panel, the price of methadone was manipulated in two separate conditions, one in which valium was concurrently available at a fixed price (FR 32) and a second in which methadone was the only drug available. In the right panel, the conditions were reversed. Two interesting effects were observed. First, when the price of the target drug increased, consumption of the other drug increased, suggesting a substitute relation. Second, the essential value of the target drug was enhanced by the presence of the alternative (i.e., lower $\alpha$ values), suggesting a complementary relation. The translational implication for methadone patients is that although providing methadone in clinical settings somewhat decreases valium consumption at low prices (lower $Q_0$ in the right panel of Figure 8.13), it also serves to sustain valium consumption in the face of price increases. Furthermore, decreasing availability of methadone (e.g., by raising the street price of the drug or increasing the travel distance to a methadone clinic) only makes matters worse as valium consumption increases (see left panel of Figure 8.13).

**Translating delay discounting.** Individuals who compulsively use psychoactive drugs, gamble, or overeat on average discount delayed rewards more steeply than do demographically matched non–drug

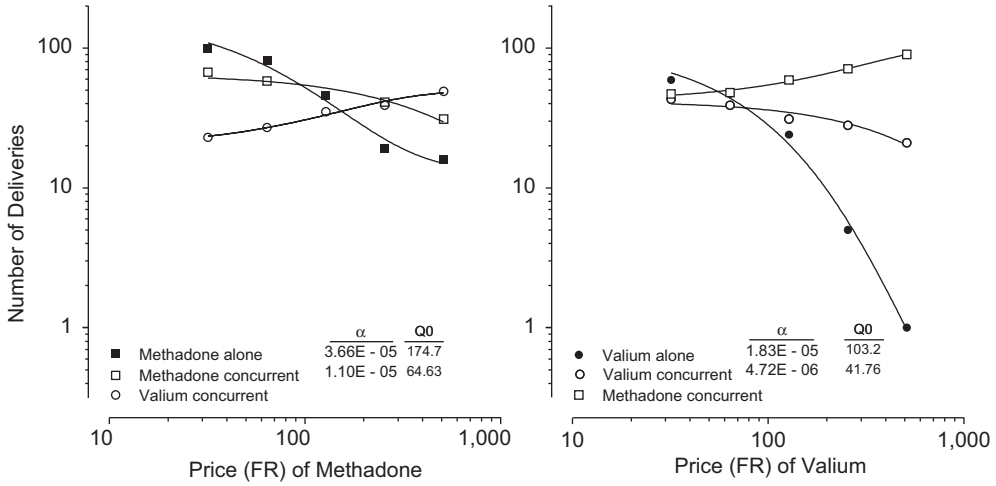



**FIGURE 8.13. Mean daily consumption by human subjects of methadone and valium as a function of the price (fixed-ratio [FR] schedule) of methadone (left panel) or valium (right panel). The cross-price changes in consumption of valium are shown on the left at a fixed price of 32; the cross-price changes in consumption of methadone are shown on the right at a fixed price of 32. Data from Spiga (2006).**

users, nongamblers, and those who do not eat excessively (Madden & Bickel, 2010). As noted earlier, some evidence has suggested that steep discounting of delayed rewards precedes and predicts drug taking (Carroll et al., 2010) and is predictive of failure in drug treatment trials (e.g., MacKillop & Kahler, 2009). The finding that individual differences in delay discounting among rats are predictive of drug taking is presumably a function of biological differences because rats were treated identically in these studies.

A second source of individual differences in delay discounting is the environment in which an individual lives, makes choices, and experiences consequences of those choices. This class of variables has received considerably less attention in the delay discounting literature, which is somewhat surprising because experimentally produced differences in delay discounting offer an opportunity to investigate whether steep delay discounting is causally related to subsequent addictive behavior. If so, then procedures that render discounting curves more shallow may hold promise for preventing the development of addictions.

Applied researchers may not want to wait for current basic research to investigate whether experimentally altering the degree to which an animal discounts delayed outcomes affects subsequent addiction-related behavior. There are compelling reasons to believe that steeply discounting delayed behavioral outcomes plays a role in the decision to live for the moment and ignore delayed aversive side effects of present-oriented hedonism. These arguments have been well laid out for substance use (e.g., Bickel & Marsch, 2001) and pathological gambling (Madden, Francisco, Brewer, & Stein, 2011; Rachlin, 1990), and components of these arguments could be applied to a host of disorders including obesity (Rasmussen et al., 2010), attention-deficit/hyperactivity disorder (see Chapter 15, this volume), and failure to self-manage tic disorders and obsessive–compulsive disorder (both of which involve a preference for immediate negative reinforcement over delayed improvements in quality of life). In the sections that follow, we explore the effects of three systematic environmental contingencies that have been arranged in the basic research laboratory and have proven effective in decreasing delayed reward discounting.

**Teaching delay tolerance.** Mazur and Logue (1978) taught pigeons to better tolerate delays to a larger–later reward (see Logue, Rodriguez, Peña-Correal, & Mauro, 1984, for similar findings). In their study, pigeons first chose between large and small food reinforcers, both delayed by 6 seconds. When the birds strongly preferred the larger

reinforcer, the delay to the smaller one was gradually decreased over a period of about 1 year, all the while maintaining preference for the LLR. As noted, at the end of this training pigeons more often chose a LLR over a SSR when compared with control pigeons that did not receive this delay tolerance training. Similar interventions have successfully been used with preschool children described by their teachers as being impulsive (Schweitzer & Sulzer-Azaroff, 1988), children diagnosed with attention-deficit/hyperactivity disorder (Binder, Dixon, & Ghezzi, 2000), and adolescents with traumatic brain injury (Dixon & Tibbets, 2009). The latter demonstrations have been somewhat limited in that no data were reported on how long the effects of training lasted and to what extent choices made outside of the training setting were affected by this training. Thus, these studies may be regarded as proof of concept, with much work remaining to be done to evaluate and ensure the effects of training will last and will generalize to a wide variety of choice contexts.

**Reward bundling.** In their text *Midbrain Mutiny: The Picoeconomics and Neuroeconomics of Disordered Gambling,* Ross, Sharp, Vuchinich, and Spurrett (2008) described reward bundling as the most important strategy that an individual can learn in the avoidance of addictions such as substance abuse or pathological gambling (see also Ainslie, 1992). Bundling rewards means considering not just the consequences of the present choice but the consequences of repeatedly receiving the same outcome and repeatedly not receiving the outcome forgone well into the future.

The top panel of Figure 8.14 illustrates decision making without use of the reward bundling strategy—that is, the individual at Time 1 considers the SSR and LLR as though this were the only choice ever made and these were the only consequences ever experienced. Considered as single outcomes, the steep discounter shown makes the impulsive choice because the discounted value of the LLR falls below the undiscounted value of the SSR.

The middle panel of Figure 8.14 illustrates two reward bundles that a decision maker, situated in time at Time 1, might choose between. The first bundle is composed of three SSRs (SSR bundle);

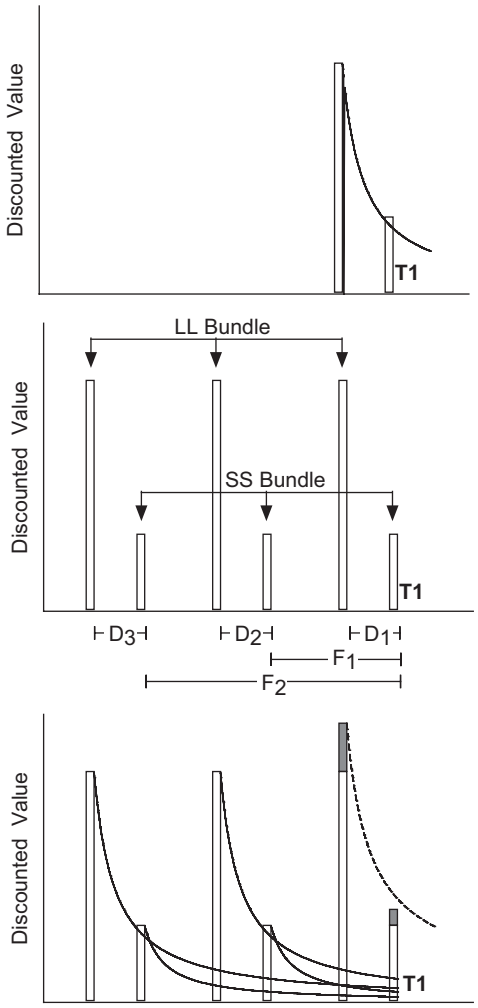



FIGURE 8.14. Delayed reward bundling. The top panel shows the discounted value of larger–later reinforcer (LLR) relative to immediately available smaller–sooner reinforcer (SSR). The middle panel illustrates that three rewards will be bundled; choosing the SSR results in the organism obtaining the SSR on the present trial and the next two trials (i.e., following future intervals F1 and F2). Likewise, choosing the LLR bundle results in three LLRs across three trials, the first following the programmed delay (D1), the second after F1 and D2, and the third after F2 and D3. The bottom panel shows the discounted values of the two bundles. The value of the three SSRs is given by the height of the SSR bar with the discounted values of the next two SSRs added in the shaded area. The discounted value of the LLR bundle is given by the dashed discounting curve. T1 = Time 1.

one delivered now (at Time 1) and the others in the future (after delays $F_1$ and $F_2$). When the individual chooses the SSR bundle, he or she enjoys the immediate benefits of the SSR and is committed to receiving the remaining two smaller rewards in the future (and not receiving any of the LLRs). The second reward bundle is composed of three LLRs, one delivered after the delay ($D_1$) and the others in the future ($F_1 + D_2$ and $F_2 + D_3$).

When the three separate LLRs are combined into a single bundle, the value of the LLR bundle is determined by the sum of the discounted values of all rewards in the bundle. This is illustrated in the bottom panel of Figure 8.14. Consider first the value of the SSR bundle. The value of this bundle is the value of the immediate reward (the open portion of the SSR proximal to Time 1) plus the sum of the discounted values of the next two small rewards in the bundle. We summed these two discounted values and added this to the height of the SSR bar nearest Time 1 (the filled portion of this bar).

The benefit of reward bundling occurs when the discounted values of the three LLRs are summed. The dashed curve in the bottom panel of Figure 8.14 shows the summed discounted value of the three bundled LLRs. Now the discounted value of the LLR bundle exceeds the value of the SSR bundle, and the impulsive choice is avoided. Experiments with both humans (Kirby & Guastello, 2001) and rats (Ainslie & Monterosso, 2003) have illustrated that when rewards are bundled, impulsive decision making is decreased. To our knowledge, no attempts have been made to evaluate the effects of reward bundling on human decision making in an applied setting.

**Engaging executive functioning.** A good deal of evidence has supported the hypothesis that hyperactivation of limbic structures and hypoactivation of frontal cortex structures underlay addiction (e.g., Baler & Volkow, 2006). Limbic structures such as the amygdala and ventral striatum (which includes the nucleus accumbens) are activated by positive surprises and stimuli signaling these better than expected events (e.g., Schultz, 2002). These limbic structures are hypersensitive to drug rewards and drug cues in addicted populations (e.g., Bechara, 2005). Limbic structures appear to be more active when humans make impulsive choices in a delay discounting experimental preparation (e.g., McClure et al., 2004). By contrast, greater relative activation in the prefrontal and parietal cortex is observed when humans select LLRs (McClure et al., 2004). The latter structures are associated with executive functioning (i.e., cognitive activities that facilitate control of present behavior by anticipated future consequences; Barkley, 1997) and appear to be hypoactive in drug-dependent populations (e.g., Hester & Garavan, 2004).

Bickel et al. (2011) suggested that steep delay discounting is the product of executive system dysfunction, which may owe its origin to atrophy resulting from lack of use. In their experiment, Bickel et al. assessed delay discounting in stimulant users before and after they came to the lab and extensively practiced executive functioning tasks that targeted attention and memory. Participants in the executive function training group were paid on the basis of their performance on the attention and memory tasks, and training continued until their performance reached asymptote. A control group was paid a yoked amount for completing a structurally similar task that did not engage attention or memory skills. After training, the executive function group demonstrated significantly more shallow delay discounting than did the control group. This improvement was, interestingly, constrained to delay discounting, because no effects of executive function training were detected on six other nondiscounting measures. This finding is an intriguing one that will need to be systematically replicated in other labs and with other populations.

Clearly, more basic research is needed on the reliability, duration, and generalization of these three methods for experimentally decreasing the degree to which delayed rewards are discounted. The results of these studies should inform clinical work that targets for change the wide varieties of impulsive decision making. However, applied researchers have already begun to teach delay tolerance as a means of affecting socially important behavior (e.g., Hanley, Heal, Tiger, & Ingvarsson, 2007; Chapter 15, this volume). We applaud these

efforts and look forward to continued cross-pollination between applied and basic laboratories.

## TRANSLATING BEHAVIORAL ECONOMIC PRINCIPLES TO OTHER APPLIED SETTINGS

As the breadth of this volume demonstrates, behavior analysts work in a broad array of settings in which behavior is an obstacle to personal and societal well-being. Thus, the behavioral economic principles discussed here apply beyond the study and treatment of addiction, although addiction is clearly the area in which these principles have most often been used. A second area in which behavioral economic principles have begun to be translated is in the treatment of behavior problems among individuals diagnosed with autism or intellectual or developmental disabilities. In the sections that follow, we outline some of the translations that have been undertaken with this population, and we hope that these examples will occasion new translational research by our readers.

### Evaluating and Enhancing Value

Applied behavior analysts who work with individuals with autism and intellectual or developmental disabilities have developed techniques designed to determine the relative efficacy of therapeutic reinforcers (e.g., Fisher et al., 1992). These repeated-choice techniques, often referred to as *preference assessments,* were developed to determine quickly the most effective reinforcer that may be arranged in an operant contingency with adaptive, prosocial behavior (Poling, 2010). However, several studies have suggested that the results of these preference assessments may not predict responding when access to the reinforcer is increasingly constrained (e.g., DeLeon, Iwata, Goh, & Worsdell, 1997; Francisco, Borrero, & Sy, 2008), for example, when the schedule of reinforcement is thinned, and the reinforcer is gradually faded from use.

The results of a preference assessment do not parallel anything on a behavioral economic demand curve. Although the price of each reinforcer is very low in a preference assessment (e.g., simply pointing to the preferred item results in its delivery), the results of this assessment do not correspond to peak consumption ($Q_0$) because the participant is not given relatively unconstrained long-duration access to the reinforcer. If the participant was (e.g., the participant was placed in a room with all of the potential reinforcers and the time spent with each before the participant elects to leave the room was measured), then peak consumption would be assessed; however, as noted earlier, peak consumption is not predictive of essential value.

Valid assessments of essential value in applied settings may be impractical. Multiple long-duration sessions in which consumption of a single reinforcer is increasingly constrained would be time spent not addressing the individual's behavioral deficits. Moreover, little is known about the stability of the essential value of nonessential, nonaddictive reinforcers such as access to a particular toy or a specific snack. Thus, it is possible that after spending weeks assessing a complete demand curve for a cheese puff, the participant will no longer work for cheese puffs, but will work for a chocolate cookie. Thus, the demand-analysis methods outlined earlier in the chapter may have little utility in applied settings.

Addressing this concern, Roane (2008) suggested that PR schedules may hold promise for assessing something akin to essential value because they allow a rapid assessment of the highest price an individual will pay to obtain the next reinforcer. PR schedules are most often arranged so that the number of responses required for the next reinforcer increases between reinforcers. The last response requirement completed before the participant stops responding for a criterion period is the PR breakpoint, or the highest price that will be paid to consume the next reinforcer. Several human studies that have assessed both have suggested that PR breakpoints and $P_{max}$ values are positively correlated (Bickel & Madden, 1999b; Jacobs & Bickel, 1999; Johnson & Bickel, 2006); however, two animal studies in which rats' PR breakpoints and $P_{max}$ values were assessed with food, water, and a fat solution revealed a significant positive correlation in only one of four assessments (Madden et al., 2007a, 2007b). Furthermore, caution is warranted in using PR schedules among individuals who engage in maladaptive behavior maintained by escape (e.g., escape from the caregiver's demands to comply with instructions, engage in

academic tasks, etc.; see Poling, 2010). For example, DeLeon, Williams, Gregory, and Hagopian (2005) found that signaled transitions from low to high reinforcer prices resulted in punctuated increases in maladaptive behavior.

## Random-Ratio Schedules

A different tactic for arranging effective reinforcers is to focus less on determining the value of the reinforcer and more on arranging a schedule of reinforcement that yields inelastic demand for a preferred reinforcer (as identified by a preference assessment). Recall the results of the Madden et al. (2005) pigeon study in which demand for food under RR schedules was significantly more inelastic than was demand for the same type of food arranged according to equivalent FR schedules (Figure 8.8). If Madden et al.'s findings may be generalized to humans in applied settings, then arranging a RR schedule will meet the goal of identifying a contingency that better maintains behavior when access to the reinforcer is constrained. Suggestive evidence was reported by De Luca and Holbourn (1992) who arranged a variable-ratio schedule of reinforcement for obese children to pedal a stationary bike. When pedaling rates were compared with those of a different group of obese boys from a prior study under FR schedules (De Luca & Holbourn, 1990), peak rates were found to be higher under variable ratio than FR. Indeed, as reinforcer price was increased by increasing the variable-ratio schedule value, the obese boys' pedaling rates approximated those of nonobese boys. Notably, these peak rates were maintained over long periods of many sessions with the outcome that the obese children lost weight and improved their fitness.

Administering a RR schedule in an applied setting can be as simple as the participant's rolling a die or pulling a poker chip from a bag; if the criterion number or color is revealed, then the reinforcer is delivered. A potential additional benefit of the RR schedule is that it may decrease the probability of problem behavior associated with transitions from preferred to nonpreferred activities (e.g., McCord, Thomson, & Iwata, 2001). When pigeons transition from signaled low to high prices under a FR schedule, they pause for inordinate periods of time before beginning work on the FR (Perone & Courtney, 1992); these pauses can be accompanied by aggressive behavior in pigeons (e.g., Kupfer, Allen, & Malagodi, 2008). However, a recently completed study revealed that scheduling food reinforcers according to a RR schedule ameliorated these maladaptive pauses (Brewer, Williams, Madden, & Saunders, 2012). The translational value of these findings will await empirical evaluation with humans in applied settings.

## Applied Implications of Substitutes and Complements

In our earlier discussion of open and closed economies, we noted that the essential value of a reinforcer is diminished when a perfect or partial substitute reinforcer is available either concurrently or after the experimental session. This has important implications in applied settings in which behavior occurs in a context of choice in which substitute reinforcers are either concurrently available or will soon be available. At least one applied study enrolling individuals with intellectual or developmental disabilities has reported results consistent with laboratory studies of open and closed economies (Roane et al., 2005): When a perfect substitute was available after sessions in which reinforcers were obtained according to a PR schedule (open economy), within-session consumption was lower than when these reinforcers were unavailable (closed economy). The implications of this are obvious: If therapeutic reinforcers are to establish and maintain adaptive behavior, they will be more effective if access to perfect substitute reinforcers is strictly contingent on engaging in the adaptive behavior.

Similarly, when substitutes are available concurrently, the marketplace is opened, and therapeutic reinforcers must compete with those that maintain problem behavior. Shore, Iwata, DeLeon, Kahng, and Smith (1997) turned this analysis on its head, reasoning that the reinforcer maintaining problem behavior would be less effective if it was placed into a competitive marketplace in which substitute reinforcers were concurrently available (see McDowell, 1988, for an identical suggestion derived from Herrnstein's 1970 matching law). This technique is particularly useful when the therapist does not control

the reinforcer maintaining the problem behavior. In the Shore et al. study, three children with intellectual or developmental disabilities engaged in self-injurious behavior that was maintained by the stimulation produced by the injurious act. Beyond preventing self-injury through restraint, the therapist cannot control this consequence. Thus, Shore et al. made available a low-price reinforcer (an item identified by a preference assessment) hypothesized to function as a substitute. In all three cases, self-injurious behavior was substantially reduced when the substitute item was available. In a subsequent condition, the price of the substitute was increased by increasing the effort expended to physically manipulate the substitute item. Consistent with the demand law, these price increases reduced consumption of the substitute item and, suggestive of a bidirectional substitute relation, increased self-injurious behavior.

Other investigators have examined functional similarity as a characteristic of reinforcers that interact as substitutes (DeLeon et al., 1997; Tustin, 1994) in people with intellectual or developmental disabilities. DeLeon et al. (1997) constructed demand functions for two individuals with intellectual or developmental disabilities in which the price of two concurrently available reinforcers increased progressively and identically across phases of the analysis. At low prices (FR 1–FR 1), the participants consumed each of the available reinforcers about equally. However, as prices increased (FR 2–FR 2, FR 5–FR 5, etc.), a clear preference sometimes emerged for one of the stimuli over the other. This preference emerged only when the two available commodities were functionally similar (e.g., cookie and cracker), not when they were functionally dissimilar (e.g., cookie and 30-second access to a mechanical toy). These investigators concluded that the simultaneous price increases magnified small differences in preference that remained undetected when costs were low and that demand for the lesser preferred similar stimuli was more elastic than that for the lesser preferred dissimilar stimuli because physically similar commodities, sharing functional properties, are more substitutable. That is, when two commodities are functionally similar, the individual can exclusively consume the more preferred item without suffering deprivation for the shared form of stimulation. When the reinforcers are functionally dissimilar, however, exclusive consumption of one deprives the person of the form of stimulation provided by the other (i.e., exclusively choosing the toy deprives the individual of any appetitive reinforcers).

Two points can be made by integrating the findings of the Shore et al. (1997) and DeLeon et al. (1997) studies. For simplicity, we refer to the reinforcer that maintains the problem behavior as $R_{prob}$ and the reinforcer that substitutes for $R_{prob,}$ and reinforces an appropriate, alternative response, as $R_{sub}$. When demand for $R_{sub}$ is elastic, and assuming that $R_{prob}$ substitutes for $R_{sub}$, then we would expect problem behavior to reemerge when the price of $R_{sub}$ is minimally increased (as it did in the Shore et al. study). The reemergence of problem behavior will also happen when demand for $R_{sub}$ is inelastic, but it will not happen until the price of $R_{sub}$ is increased more substantially. The elasticity of $R_{sub}$ is important because in applied settings it is often impractical to deliver $R_{sub}$ after every appropriate alternative response. Thus, progressively intermittent use of $R_{sub}$ is common in these settings, and one should be prepared for $R_{prob}$ to substitute for $R_{sub}$ when the price of $R_{sub}$ is increased. Second, if $R_{prob}$ is functionally similar to $R_{sub}$, then this will render more elastic demand for $R_{sub}$ (DeLeon et al., 1997) which, as noted in our first point, will further increase the probability of problem behavior reemerging when minimal constraint is placed on consumption of $R_{sub}$. Taken together, for some individuals the optimal substitute for $R_{prob}$ may be one that has a high essential value but is functionally dissimilar from $R_{prob}$.

Consistent with this analysis, in the treatment of escape-maintained problem behavior some researchers have arranged to reinforce compliance with a reinforcer that does not share any apparent functional qualities with escape, that is, a reinforcer that would be expected to function as an economic independent. For example, some researchers have successfully reinforced compliance with an edible reinforcer and have reported that edibles more effectively reinforce compliance than escape (DeLeon, Neidert, Anders, & Rodriguez-Catter, 2001; Lalli et al., 1999; Piazza et al., 1997). A question of interest

in the current discussion concerns the frequency of escape-maintained problem behavior when the price of the edible reinforcer is increased, for example, when schedule thinning is implemented to make the intervention more practical. Because escape presumably does not substitute for the edible, one might expect demand for the edible to be more price inelastic than if compliance were reinforced with escape. One would also expect to see problem behavior reemerge at lower prices when the therapeutic reinforcer is escape than when it is an edible. Said less technically, and from the client's perspective, "If the therapeutic reinforcer is escape, why would I comply with several task requests to earn a break? I can get the same thing by engaging in problem behavior." When the therapeutic reinforcer is an edible for which there are no available substitutes, then engaging in problem behavior is not a viable alternative.

This hypothesis was tested in an unpublished study by DeLeon et al. (2009). The study compared three treatments of escape-maintained problem behavior in five individuals with intellectual disabilities. Across all three treatments, problem behavior produced a 30-second escape from task demands, whereas task completion resulted in access to (a) a substitute for escape (i.e., a 30-second break), (b) a small edible but no break, or (c) a choice between (a) and (b). A PR schedule increased the price of the therapeutic reinforcer until problem behavior increased to at least 50% of baseline. In four of the five participants, arranging a nonsubstitutable therapeutic reinforcer yielded less problem behavior as the price of that reinforcer increased.

The applied utility of complementary relations between reinforcers is largely untapped. The two general strategies are as follows. First, identify the reinforcer maintaining the problem behavior (functional analysis), and then attempt to identify consequences that may function as complements to that reinforcer. For example, if problem behavior is maintained by escape, then one might look for complementary conditions that increase the value of escape. That is, in applied settings escape involves escape from a nonpreferred setting followed by a transition to another setting. What is that other setting? Is it enhancing the value of escape? Can it be eliminated?

The second general strategy is used when one is attempting to enhance the value of a therapeutic reinforcer. Is it possible to make available a noncontingent complementary good that will increase the essential value of the therapeutic reinforcer? For example, if chips are the reinforcer, will the noncontingent availability of chip dip increase the ability of chips to maintain behavior? If attention is the reinforcer, will noncontingent access to social activities (e.g., playing a game) enhance the essential value of attention?

## CONCLUSION

The application of microeconomic theory to conceptualizing and understanding operant behavior as consumer choice has brought new measures (e.g., total consumption) and variables (e.g., substitute and complementary reinforcer relations) to the science of behavior analysis. Most of these investigations have been conducted in laboratory settings, but the topics studied in these settings (e.g., drug seeking and drug taking) have always been less than a half-step away from application. The potential of behavioral economic principles to influence behavior in applied settings in important ways should be clear from this chapter and the beginnings of work being done in these settings today. As the basic laboratory continues to reveal new functional relations, we look forward to the continued translation of these relations to bettering the human condition.

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