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Behavioral Economics and the Analysis of Consumption and Choice

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The relatively new field of behavioral economics represents a concrete attempt to apply the science of behavior to understand the data of economics, as proposed by Skinner (1953). The concepts from micro-economic theory are explored with methods to study 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 micro-economic theory has been a fruitful area of research (Hursh, 1980; Kagel et al., 1975; Kahneman, Slovic, & Tversky, 1982; Lea, 1978; Rachlin, Green, Kagel, & Battalio, 1976; Rachlin & Laibson, 1997; Thaler & Mullainathan, 2008) and provides a translational framework for extending principles derived from laboratory studies to an understanding of consumer choice observed in whole communities. Practical application of these methods pave the way for empirical research to test the implications of public policy that seek to influence the choices of people in society (Magoon & Hursh, 2011).

There are several points of converge between economics and behavioral psychology. One is a common interest in the value of goods, defined as reinforcers by the behaviorist, and defined 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 different competing reinforcers. In this review, we will focus more on the utility of economic methods of analysis and consistent functional relationships than on hypothetical economic concepts, such as utility functions, indifference curves, and optimal choices. What emerges is an important extension of behavioral principles and a functional analysis of economic processes (Hursh, 1980, 1984).

Concepts of behavioral economics have proven useful for understanding the environmental control of overall levels of behavior for a variety of commodities in closed

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systems (Bickel, DeGrandpre, Higgins, & Hughes, 1990; Bickel, Madden, & DeGrandpre, 1997; Foltin, 1992; Hursh, 1984; Lea, 1978; Lea & Roper, 1977; Rashotte & Henderson, 1988) and the factors that control the allocation of behavioral resources among available reinforcers (Hursh, 1980, 1984; Hursh & Bauman, 1987). A closed system or *closed economy*, as it is called, is a situation in which there is no other source of the commodity of interest, outside of the environment being studied. Behavioral economics, as practiced by students of operant conditioning and behavior analysis, has borrowed concepts from micro-economics, especially consumer demand theory and labor supply theory (Allison, 1983; Allison, Miller, & Wozny, 1979; Lea, 1978; Kagel, Battalio, & Green, 1995; Rachlin, Green, Kagel, & Battalio, 1976; Staddon, 1979; see Watson & Holman, 1977, for a review of relevant micro-economic 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 our attention to new phenomena previously ignored and new functional relations previous unnamed. In this chapter, behavioral economics is applied to the analysis of consumption of various reinforcers and the responding that produces that consumption. This chapter provides some basic groundwork that will serve as a primer for understanding behavioral-economic concepts that could be applied to understanding of a range of behaviors in the laboratory and clinical settings and we will illustrate extensions to human behavior that could advance empirical public policy.

Value of Reinforcers

One of the most important contributions of behavioral economics has been to redirect our attention to total daily consumption of reinforcers as a primary dependent measure of behavior and the way consumption varies with the cost of reinforcers provides a fundamental definition of the value of those reinforces. In this context, responding is regarded as a secondary dependent variable that is important because it is instrumental in controlling consumption of valued reinforcers. Consideration of consumption as a primary factor required a major methodological shift. In most behavioral experiments, the practice has been to control "drive" by imposing some deprivation schedule. For example, animals reinforced by food are held to 80% of free feeding weight by limiting daily consumption and supplementing the amount of food earned in the test session with just enough food to hold body weight within a restricted range. This strategy was designed to hold "drive" constant and eliminate a confounding factor. Inadvertently, the practice also eliminated one of the major factors controlling behavior in the natural environment, defense of consumption. Under conditions of controlled drive, responding is not instrumental in determining daily consumption and is directly related to the rate of reinforcement in the experimental session (Herrnstein, 1961). This strategy of controlling deprivation or daily consumption, independent of behavioral changes, is what Hursh has defined as an "open economy" (Hursh, 1980, 1984); the situation is not a closed system with regard to sources of the reinforcers. In more recent experiments, control of deprivation has been eliminated and subjects have been allowed to control their own level of consumption, what Hursh has termed a *closed economy*, or a closed system in which there is no outside source of the reinforcer under study. The finding is that radically different sorts of behavioral adjustments occur in these two types of economies, especially when the reinforcer is a necessary commodity like food or water (see Bauman, 1991; Collier, 1983; Collier, Johnson, Hill, & Kaufman, 1986; Foster, Blackman, & Temple, 1997; Hall & Lattal, 1990; Hursh, 1978, 1984; Hursh & Natelson, 1981; Hursh, Raslear, Bauman, & Black, 1989; Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988; LaFiette & Fantino, 1989, 1989; Lucas, 1981; Raslear, Bauman, Hursh, Shurtleff, & Simmons, 1988; Roane, Call, & Falcomata, 2005; Zeiler, 1999).

Most studies of food reinforcement have been conducted in open economies and suggest that food consumption is easily reduced by changes in effort or rate of reinforcement. However, studies of food reinforcement in closed economies provide a striking contrast of persistent behavior that is very resistant to the effects of reinforcer cost (see Hursh, 1978; Bauman, 1991; Foltin, 1992). On the other hand, for those interested in drugs as reinforcers, most experiments involving drug self-administration have arranged a closed economy for the drug reinforcer; all drug administrations are response dependent during the period of experimentation (Johanson, 1978; Griffiths, Bradford, & Brady, 1979; Griffiths, Bigelow, & Henningfield, 1980; Hursh & Winger, 1995). It is important that when comparing drug-reinforced behavior to behavior reinforced by another reinforcer, such as food, that a closed economy be arranged for that reinforcer as well. The behavioral difference between open and closed economies is best understood in terms of demand for the reinforcer, discussed next.

Demand Curve Analysis

The relationship between reinforcer cost and reinforcer consumption is termed a "demand curve." As the cost of a commodity increases, consumption decreases, illustrated in Figure 12.1, left panel. The rate of decrease in consumption (sensitivity to price) relative to the initial level of consumption, is called "elasticity of demand." When consumption declines slowly with proportionately large increases in price, we define that as "inelastic demand." For this to occur, total responding must increase as cost increases (Figure 12.1, right panel). For example, when the price of gasoline increased three-fold during the 1970s from 33 cents a gallon to over one dollar a gallon, consumption decreased by only 10% (Nicol, 2003). This was an example of inelastic demand and the result was that a larger share of household budgets was allocated to gasoline than was before. Other commodities, such as luxury goods (unnecessary for survival, for example) or goods with many substitutes (such as one brand of peanut butter, for example), have steeply sloping demand curves. Demand for such goods are generally "elastic" and consumption is highly sensitive to price.

The difference in demand between inelastic and elastic goods is easily demonstrated in the laboratory. Figure 12.2 depicts the consumption by monkeys of saccharin sweetened water with an alternative source of water and consumption of food pellets without alternative food. The demand curve for saccharin is generally elastic and is steeply sloping, while the curve for food is generally inelastic and decreases more slowly. In the figure, the price of each commodity (food or saccharin) was

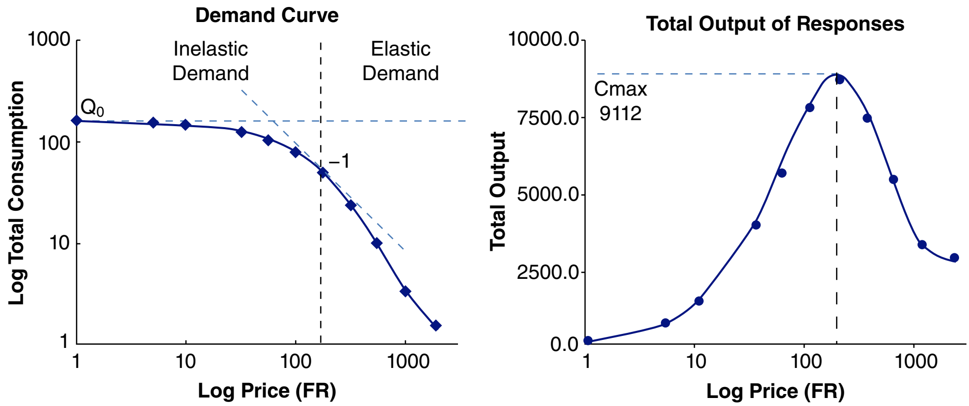

Figure 12.1 Left panel: diagrammatic demand curve showing the usual shape and increasing elasticity across the demand curve. The vertical line marks the point of unit elasticity (slope = −1) which is the transition from inelastic to elastic demand. The level of demand is denoted as the y-intercept or the quantity consumed at zero price (Q_0). Right panel: diagram of total daily consumption that would be required to support the levels of demand shown in the left panel. The vertical line marks the point of unit elasticity and the peak response output. The price at that point is called P_{max}.

gradually increased from ten responses per reinforcer to over 372 responses per reinforcer in a closed economy. As a corollary to the differences in the demand curves, total responding for food increased over a broad range while responding for saccharin generally decreased over the same range. The distinction between elastic and inelastic reinforcers defines a continuum. Consumption of all reinforcers becomes elastic if the price is elevated sufficiently; the difference between reinforcers can be specified in terms of the price at the point of transition between inelastic and elastic demand and coincides with the peak of the response rate functions (P_{max}) shown in the right panel of Figure 12.2 (dashed lines). If that transition occurs at relatively low prices, then demand for that reinforcer is generally more elastic than demand for a reinforcer that sustains response increases over a broad range of prices. As we will see later, there is a mathematical model that fits these curves and a single rate constant in the model that determines the P_{max} value.

Carroll (1993) used demand curves to demonstrate that the addition of a saccharin reinforcer concurrent with a PCP (Phencyclidine) reinforcer had the effect of increasing the elasticity of demand for PCP, increasing the slope of the demand curve and decreasing the price at which responding reached its peak. In general, demand curves for drug reinforcers conform to the same nonlinear, decreasing function typified by those in Figure 12.2 and responding is an inverted U-shaped function of price (see below for details; also see review by Bickel, DeGrandpre, Hughes, & Higgins, 1991). As discussed by Bickel, DeGrandpre, and Higgins (1993), elasticity of demand may be a useful basic metric for comparing the value of different reinforcers, such as the abuse liability of drug reinforcers, and for assessing the potency of interventions to reduce demand for drugs and other reinforcers.

Measuring Demand

In order to use elasticity of demand as a basic yardstick for evaluating "motivation" for reinforcers, the conditions for measuring demand must be precisely specified. This includes clear definitions of the two primary variables, consumption, and price. Hursh (1980, 1984, 1991; Hursh et al., 1988) has proposed that consumption be measured in terms of total daily intake. The simplest measure of total daily consumption is a count of the number of reinforcers that have been consumed—total number of food pellets, drinks of water, or injections of a drug, for example. This approach naturally leads to a simple definition of price as the cost in terms of responses (or amount of time) required to obtain each reinforcer, which is normally specified as the value of the fixed-ratio (FR) schedule of reinforcement. For human subjects, it may be specified as the amount of money for each package of the reinforcer. The demand curve is simply the change in the number of reinforcers earned as a function of increases in the FR schedule, the cost of each reinforcer. In some experiments, the cost may be the amount of time spent working for the reinforcer and would be the value of the fixed-interval (FI) schedule of reinforcement.

As depicted in Figure 12.2, demand curves are seldom linear so precisely specifying slope requires a nonlinear function. A basic exponential function appears to adequately describe most demand curves when plotting the log of consumption as a function of cost (Hursh & Silberberg, 2008):

$$\log Q = \log Q_0 + k(e^{-\alpha\cdot(Q_0\cdot C)} - 1) \quad (1)$$

The independent variable is Cost (C) measured either as responses or units of time per reinforcer. Log of consumption ($\log Q$) is a function of Cost and is maximal at

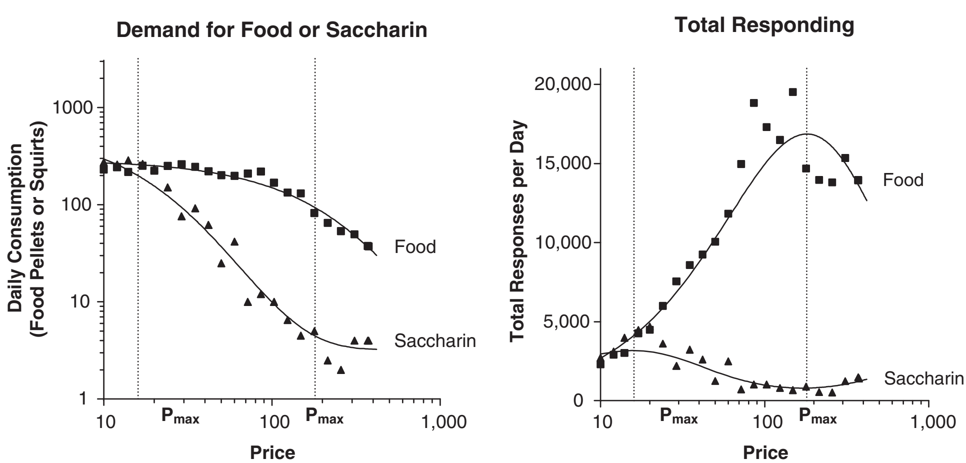

Figure 12.2 Left panel: two demand curves by rhesus monkeys working for either food (squares) or saccharin sweetened water (triangles). The functions show the total number of reinforcers earned (consumption) each day under a series of fixed-ratio (FR) schedules (crices) that ranged from FR 10 to FR 372. Right panel: daily output of responding that accompanied the levels of consumption shown in the left panel. The curves were fit with an exponential equation (Hursh & Roma, 2013).

zero cost (log Q_0) and specifies the highest level of demand. The rate constant, α, determines the rate of decline in relative consumption (log consumption) with increases in cost (C). The value of k is a scaling constant that reflects the range of the data and is generally set to a common constant across comparisons. The slope of the demand curve, elasticity, when k is constant is determined by the rate constant, α. The value of α determines the *essential value* of the reinforcer or the sensitivity of consumption to changes in cost.

It should be noted that the form of a demand curve may be critically dependent on the dimensions of the good purchased. In a study by Hursh et al. (1988), two groups of rats earned their daily food ration responding under FR schedules ranging in size from 1 to 360. For one group, the reinforcer size was one food pellet; for the other, it was two. Although the only difference between groups was the size of their food reinforcer, the demand curves that were generated differed in Q_0 and in slope. Equation 1 applied to those data provides a single estimate for the rate constant α because the equation considers differences in reinforcer size that change baseline consumption at zero price (Q_0) and incorporates the value of Q_0 in the exponent of the exponential as a component of price.

Stated another way, when commodities differ in size, it takes varying amounts of each to reach satiation reflected in Q_0 and, therefore, differences in the true cost required to defend the level of baseline demand; it takes more small packages to equal the quantitative value of a larger package. By standardizing price as ($Q_0 \times C$), Equation 1 isolates that component of elasticity due entirely to differences in essential value, α.

This consideration of the size of the reinforcer as a component of price is identical to the practice of providing unit price equivalence values in the grocery store—the true price of a good can be raised by charging more for each package or by reducing the size of each package forcing the customer to buy more packages to meet their needs. Equation 1 automatically considers both of these kinds of price manipulation in the expression $Q_0 \times C$.

Hursh and Winger (1995) proposed a similar way to eliminate scalar differences by expressing price in terms of the number of responses per 1% of maximal consumption, what we call Q_0 (see also Peden & Timberlake, 1984). The approach used here does not require rescaling the data since the conversion is inherent in the demand equation. More importantly, the exponential equation fulfills the goal of having a single parameter (α) to scale elasticity of demand, our basis for defining essential value considering the range of consumption (k).

Sensitivity to price is specified by α and is inversely proportional to essential value (EV). In order for EV to be a valid metric of value across experiments, the formulation must consider the value of k that establishes the span of the consumption data in the experiment. That formula is given in Equation 2:

$$\mathrm{EV} = 1/(100 \cdot \alpha \cdot \mathrm{k}^{1.5}) \tag{2}$$

This definition of value may be used to scale essential value for different reinforcers across a range of experiments and is closely related to the price at which demand elasticity is −1 and overall responding is maximal, the price point called P_{max}. This P_{max} is defined for demand in normalized units of consumption with all levels of consumption expressed as a percent of maximal consumption ($Q_0 = 100\%$), and price is in normalized units of cost per 1% unit of consumption ($C \times Q_0 / 100$). For an approximation of P_{max} for non-normalized demand, replace the 100 in the formula with the estimated value of Q_0.[1]

Comparing Reinforcers in Terms of Demand

The demand for three drugs self-administrated by monkeys were compared by Winger, Hursh, Casey, and Woods (2002). The study compared demand for three NMDA antagonists that differed systematically in time of onset to peak drug effect. Ketamine, PCP, and dizocilpine were measured to have times to peak visible physiological effects of 1, 10, and 32 min, respectively. The exponential demand equation permitted a direct comparison of elasticity of demand for these three drugs, shown in Figure 12.3. The figure compares best-fit demand curves for the three drugs using Equation 1. First, note that each drug was delivered using two or three different doses and that separate demand curves are fit to each dose. However, the exponential demand equation isolated the dose differences in the Q_0 parameter so that sensitivity to price, α, was constant across doses of the same drug. Second, Figure 12.3 shows that essential value was not directly related to potency; the lowest potency drug, ketamine, was reinforcing at unit doses 10 times higher than the highest dose of dizocilpine, yet had an α (sensitivity to price) that was one-fourth that for dizocilpine and a higher essential value. Figure 12.3 illustrates the utility of using demand curve analysis and exponential demand to scale psychoactive drugs for essential value and abuse liability. Hursh and Roma (2013) reported the results of demand curve studies of a range of drug and non-drug reinforcers and the results suggest a direct relationship between essential value and the abuse potential of drugs. Put another way, drugs with comparatively high sensitivity to price (large values of α and low essential value) would be expected to have lower abuse liability in the open market because of competition from cheaper or more potent substitutes.

Sensitivity to price or α is inversely related to *essential value* and P_{max}. That relationship appears to hold for the three drugs reported in Figure 12.3. The essential value or EV (Equation 2) was 252, 212, and 51 for ketamine, phencyclidine, and dizocilpine, respectively. Interestingly, EV was inversely related to the average time to onset of peak effect, shown in Figure 12.4. In other words, the value of these drugs as a reinforcer and the sensitivity of consumption to the prevailing price was controlled by the speed with which the drugs had their psychoactive effect, a relationship that mirrors numerous studies showing that the strength of reinforcement is modulated by delay of reinforcement using food and other reinforcers (Hursh & Fantino, 1973; Grace, Schwendiman, & Nevin 1998; Mazur, 1985; Mazur et al., 1985; Tarpy & Sawabini, 1974; Woolverton & Anderson, 2006). In behavioral terms, essential value is an inverse function of delay to drug reinforcement. This leads to the practical implication that pharmaceutical manipulations that delay the onset of drug effects may be useful manipulations to reduce abuse liability of therapeutic drugs, such as opiates for treatment of pain.

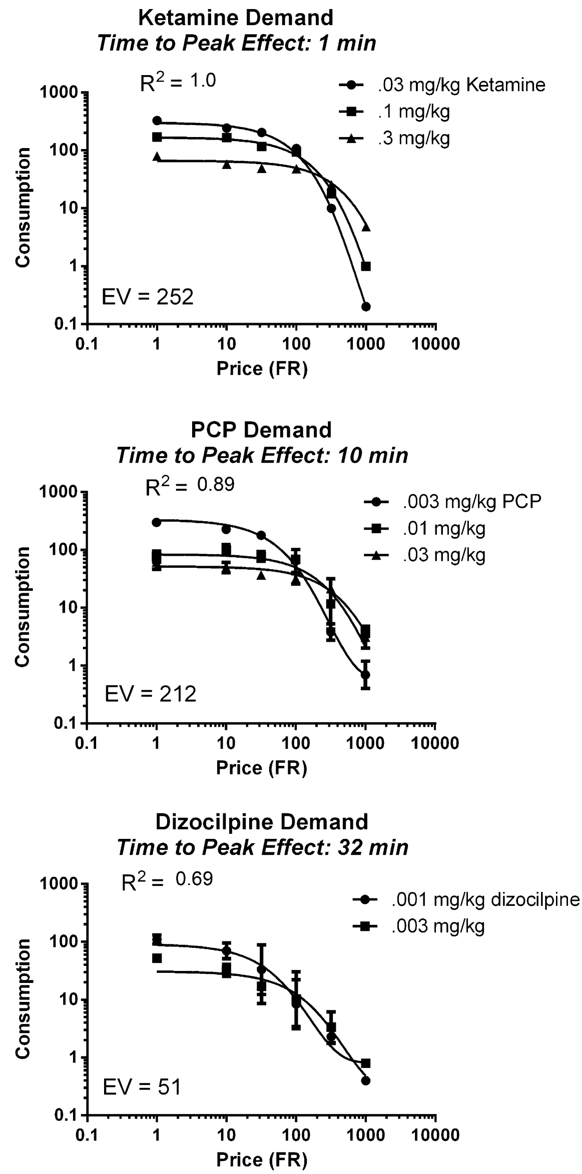

Figure 12.3 Demand curves (see Equation 1) fit to average consumption of three drugs self-administered by rhesus monkeys. The drugs were ketamine, phencyclidine, and dizocilpine. Also shown are the essential value for each drug (Equation 2).

Factors That Alter Demand and Choice

Elasticity of demand is not an inherent property of the reinforcer. For example, one of the primary differences between open and closed economies is elasticity of demand. While demand for food is inelastic in a closed economy (see Figure 12.2) where the subject controls its own intake and no supplemental food is provided, demand for

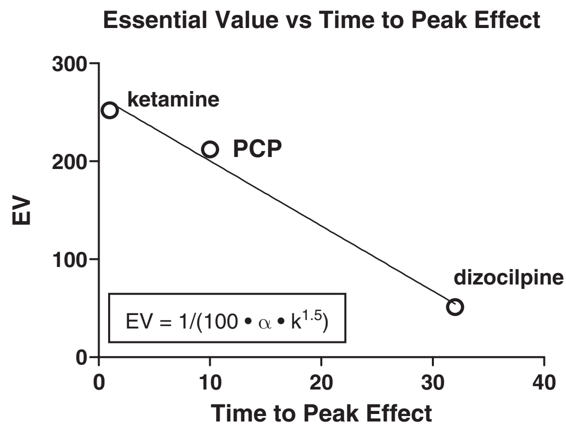

Figure 12.4 Essential value (EV) as a function of the average time to peak physiological effect of ketamine, PCP, and dizocilpine.

food in an open economy can be quite elastic. To illustrate this point, we provided a monkey access to low-cost food requiring only one response per pellet (FR 1) for 20 minutes after a 12-hour work period for food at higher prices. The price of food in the work period was increased to assess demand (Figure 12.4). The subject could work for food in the work period at the prevailing price or wait and obtain food at a lower price later, analogous to obtaining low cost food in the home cage within an open economy. Compared to demand for food when no low cost food was available, demand when an alternative source was available was much more elastic with α value 2.5 times greater than that for food without an alternative source. As a consequence, responding reached a peak at a much lower price, indicated as P_{max}. Comparing Figure 12.5 with Figure 12.2, one can conclude that the addition of a substitute food source functioned to convert food in the work period into an elastic commodity, very similar to the non-nutritive saccharin solution shown in Figure 12.2 and discussed above. In general, elastic demand is typical for all reinforcers studied in an open economy.

One way to understand the difference between open and closed economies is to observe that the reinforcers provided outside the work period can substitute for reinforcers obtained during the work period. This is just one example of a more general set of interactions that can occur among commodities available simultaneously or sequentially in the course of the subject's interaction with the environment. Within a behavioral-economic framework, reinforcer interactions are classified into several categories, illustrated in Figure 12.6. If we think of reinforcers as collections of attributes, we can represent those attributes as a "set" or circle in Figure 12.6. Each quadrant illustrates two sets of reinforcer properties as Venn diagrams. Most studies of choice with animals have arranged for the alternative behaviors to provide the same, perfectly substitutable reinforcer, usually food, shown as two perfectly congruent reinforcer sets. This yields a specific kind of interaction in which the amount of behavior to each roughly matches the amount of reinforcement received from each (*the matching law*, see Davison & McCarthy, 1988). When the two alternatives require a specific number of responses per reinforcer delivery, the subjects

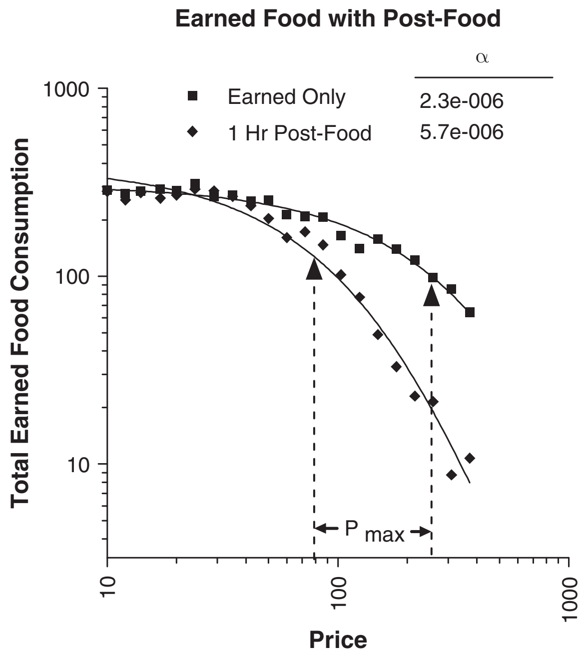

Figure 12.5 Two demand curves by a rhesus monkey for food during a 12-hr work period, either with no other source of food (closed squares) or with a 1-hr period of FR 1 food reinforcement immediately following the work period (closed diamonds). Consumption is shown as a function of the FR schedule that ranged from FR 10 to FR 372 (Hursh, 1993).

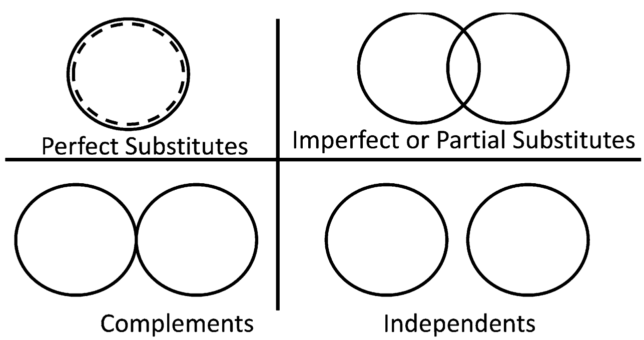

Figure 12.6 Diagram of four hypothetical forms of reinforcer interactions (see text for explanation).

generally show exclusive preference for the least costly of the alternatives (Herrnstein, 1958; Herrnstein & Loveland, 1975). This situation is much like comparison shopping for identical items from different stores; all else being equal, one will go to the store with the lowest price.

Most choices are between commodities that are not perfect substitutes (Green & Freed, 1993, 1998). The other interactions depicted in Figure 12.6 are imperfect

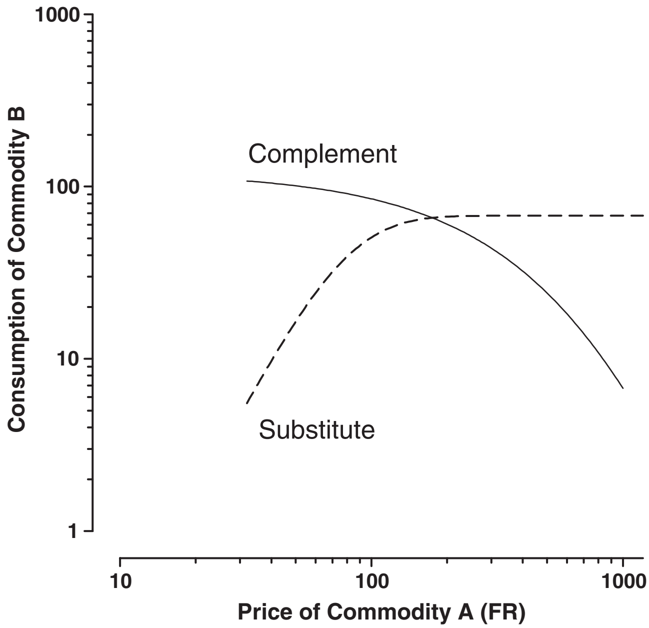

Figure 12.7 Diagram of hypothetical changes in consumption of commodity B as a function of the price of commodity A. The solid line indicates a complementary relation; the dashed line indicates a substitutable relation (Hursh & Roma, 2013).

substitutes, complements, and independent reinforcers. *Imperfect substitutes* share many features but each also poses unique features not contained in the other reinforcer. *Complements* are a special kind of reinforcer interaction in which the presence of the features of one reinforcer enhance the value of the features of the other reinforcer, that is, their individual values are "connected." Finally, *independent* reinforcers share no common functional properties, nor does the presence of one alter the value of the other; hence the sets are disconnected.

Figure 12.7 illustrates the difference between imperfect substitutes and complements. Along the x-axis is the price of commodity A; along the y-axis is the quantity of consumption of the alternative commodity B with fixed price. As the price of A increases, consumption of A decreases, the usual demand relation. If, at the same time, the consumption of B increases in response to these increases in the price of A, then B is defined as a substitute for A. If the consumption of B decreases, then B is defined as a complement of A.

Substitution

Choice between two imperfect substitutes is illustrated in Figure 12.8 (Spiga, based on unpublished data). Using a procedure similar to that reported by Spiga, Martinetti, Meisch, Cowan, and Hursh (2005), human subjects chose between methadone available after pressing one lever under an increasing series of FRs. The other alternative was a different opiate, hydromorphone, available under a constant FR schedule. Even

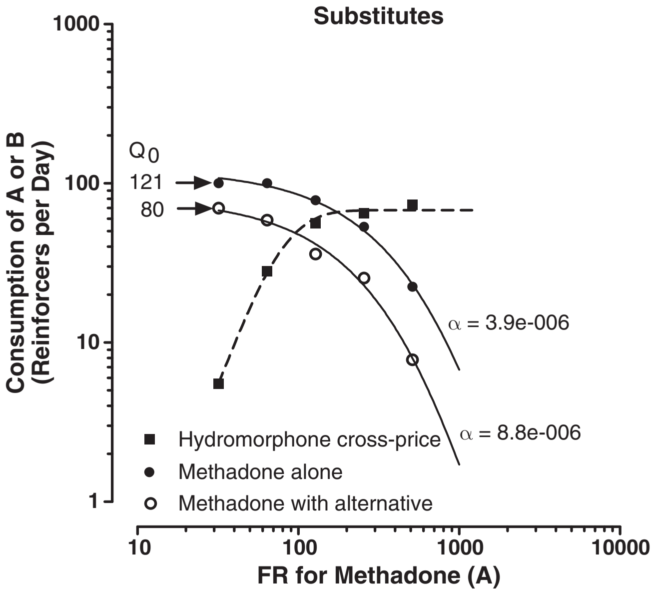

Figure 12.8 Mean daily consumption by human subjects of methadone (commodity A) and hydromorphone (commodity B) as a function of the unit price (FR schedule) for methadone, in log-log coordinates (Spiga, based on unpublished data).

at the lowest price of methadone (FR 30), some hydromorphone was consumed; as the price of methadone increased and methadone consumption decreased, consumption of hydromorphone increased as a partial substitute. The decline in methadone consumption was greater with hydromorphone available than when methadone was offered alone. However, even at the highest price of methadone (FR 512), some methadone was consumed despite the lower price of hydromorphone. This reciprocal trade-off between consumption of two reinforcers is typical of imperfect substitutes.

Of further note is the change in elasticity of methadone when hydromorphone was available as a substitute shown in Figure 12.8. Sensitivity to methadone price (α) was more than doubled when hydromorphone was available as an alternative and level of demand (Q_0) was reduced by a third (79 vs. 120). In the context of drug abuse therapy, an alternative drug reinforcer such as methadone may be used as a medical intervention designed to reduce demand or increase elasticity of demand for the drug of abuse. In this experimental model of the therapeutic process, the methadone demand is like demand for an illicit drug and the hydromorphone is like the drug therapy. Behavioral economics provides an approach to evaluation of the behavioral efficacy of this sort of drug therapy. The efficacy of different therapies would be measured in terms of their effects on the elasticity of demand for the target drug. As described above, fitting the demand equation to the observed demand curves provides a quantitative tool for specifying these changes in terms of the parameters of the demand Equation 1. In order to determine the demand for the illicit drug using actual patients requires an indirect approach using hypothetical demand curves.

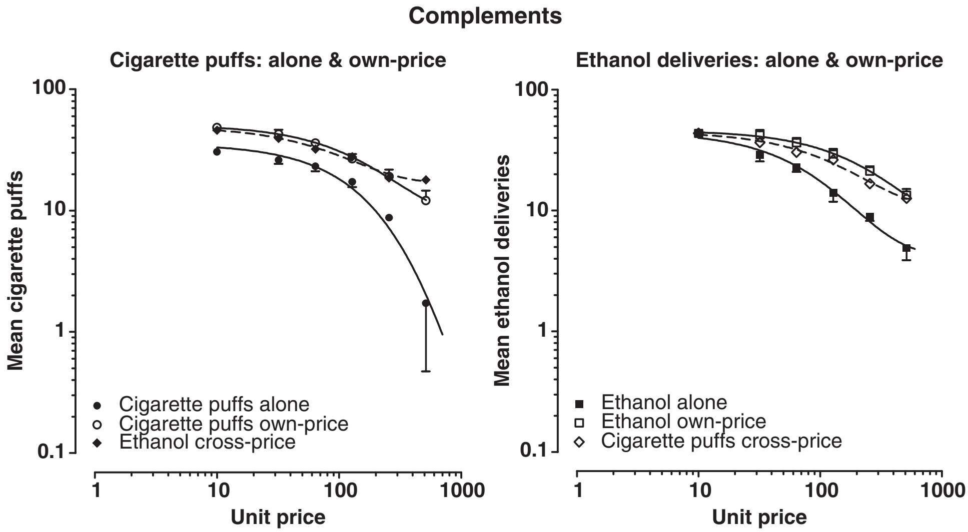

Figure 12.9 For human subjects, consumption of fixed price alternatives (commodity B, dashed lines) ethanol drinks (left filled diamond) or cigarette puffs (open diamond right) and the variable price alternative (commodity A) as a function of the fixed ratio for commodity A (open circle or open square) in log-log coordinates. Demand for cigarettes or ethanol drinks alone are shown as filled circles (left) or filled squares (right), respectively (Spiga, unpublished).

Instead of actually measuring levels of consumption under real prices, we ask subjects to estimate their levels of consumption of various illicit drugs under a series of increasing hypothetical monetary prices. The slopes of these hypothetical demand curves conform to the same exponential demand equation as actual demand curves (Hursh & Silberberg, 2008) and shifts in the rate constant of the demand curve—or changes in elasticity—can be used to track the influence of therapy to reduce overall demand (Q_0) and increase sensitivity to price (α).

Complementarity

Choice between two complements is illustrated in Figure 12.9 (Spiga, based on unpublished data). The two alternatives were ethanol drinks and cigarette puffs. In the right panel, ethanol drinks were offered at a constant price (commodity B) and the price of cigarette puffs (commodity A) was varied, either with the ethanol or alone. In the left panel, cigarette puffs were offered at a fixed price (commodity B) and the price of ethanol drinks (commodity A) was varied, either with cigarette puffs or alone. As the price of the variable price commodity A increased, decreasing consumption of that commodity, daily consumption of the fixed price alternative (B) decreased. The value of ethanol or cigarettes as a reinforcer declined as the consumption of the alternative declined. This kind of parallel decline in consumption for one commodity as the price of an alternative is increased defines the alternative as a complement. Referring back to Figure 12.6, the two reinforcers share no specific properties, but the value of each is connected to the value of the other such that one enhances the other. Note also that the demand for the variable price alternative (cigarettes on the left and ethanol on the right) was less elastic when the complement was available; the demand curves for these offered alone were consistently below the demand curves with the alternative. This further illustrates the complementary relationship between ethanol consumption and cigarette smoking.

Determining Own-Price and Cross-Price Elasticity

Own-price elasticity of demand refers to the slope of the demand curve for a commodity when plotted in the usual log-log coordinates and reflects proportional changes in consumption of the commodity with proportional changes in its own price. As noted above, demand curves are usually nonlinear and elasticity increases with price. No single number can be used to represent elasticity of demand for comparison across experiments. The demand Equation 1 provides two methods for comparing elasticities. The first is to compare the rate of change in elasticity with price. The faster elasticity increases with price, the greater the elasticity is at any given price. The *a* parameter of the demand equation represents the rate of change in elasticity of demand and is a convenient parameter for comparison across conditions and experiments. The second method uses the demand equation to compute the price that produces maximum responding, P_{max}. This is the price at which the demand curve has a slope of -1 and represents a convenient common point of reference across conditions and studies. Generally, if demand becomes more elastic, then one will observe a decrease in the price associated with an elasticity of –1 and maximum responding (P_{max}).

Cross-price elasticity of demand is the slope of the function relating the consumption of a second commodity at fixed price to the changes in price of an alternative commodity (see Figures 12.8 and 12.9). As noted above, if this function has positive slope, then the second commodity is termed a substitute for the first (Figure 12.8); if the slope is negative, then the second is termed a complement of the first (Figure 12.9); if the slope is zero, they are considered independent. An extension of exponential demand was used to fit the cross-price demand curves (commodity B) in Figures 12.8 for hydromorpone (substitute for methadone) or in Figure 12.9 for ethanol and cigarettes (complements to each other):

$$Q_B = \log(Q_{\text{alone}}) + Ie^{-\beta \cdot C_A} \tag{3}$$

where Q_{alone} is the level of demand for the constant-price commodity B at infinite price (C) for commodity A (zero consumption of commodity A), *I* is the interaction constant, β is the sensitivity of commodity B consumption to the price of commodity A, and C_A is the cost of commodity A. In Figure 12.8, the interaction term *I* was negative (-3), indicating a reciprocal or substitution relationship between consumptions of the two commodities; in Figure 12.9, the interaction terms *I* were positive (0.5 for ethanol and 0.6 for cigarettes) indicating a parallel or complementary relationship between consumptions of ethanol and cigarettes.[2]

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 reinforcer is available. Low-priced concurrently available perfect substitutes produce the largest decrease in essential value with imperfect substitutes and delayed alternatives 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 approaches to prominent models of decision-making such as Herrnstein's (1970) matching law, although extensions to qualitatively different reinforcers and to choices in the "market place" have been described (Green & Rachlin, 1991; Herrnstein & Prelec, 1992).

The Behavioral Economics of Addiction and Treatment

There are a number of economic theories suggested to explain the development of an addiction—an increasingly strong tendency to seek and consume a specific commodity (Foxall & Sigurdsson, 2011; Vuchinich & Heather, 2003). Here, the application of the demand law offers a systematic and longitudinal way to describe the neurobehavioral changes that are described as addition. Rather than attempt to construct a hypothetical process to explain the development of an addiction, we merely provide a convenient way to measure and track the process (Bickel et al., 1993; Hursh, 1991, 1993). The underlying process that leads to addiction are likely both genetic and developmental (ontogenetic) but there is no consensus on the exact balance of the two processes. Nevertheless, there is a growing literature that indicates that for some commodities extended exposure to the reinforcing properties of the item lead to progressive changes in demand (Ahmed & Koob, 1998). In a recent experiment with rodents, demand curves for infusions of cocaine were determined after a brief familiarization with the drug and then later after a two-week long history of infusions (Christensen, Silberberg, Hursh, Roma, & Riley, 2008). In parallel, demand curves for food were also obtained.

Figure 12.10 illustrates the effect of the extended history for cocaine. There was both an increase in the level of demand and a change in elasticity of demand following the extended history. Here, we focus on the change in elasticity of demand; the demand curve for cocaine has been plotted as changes in consumption, with Q_0 set as the 100% level of consumption at the lowest price (see Hursh & Winger, 1995). This figure shows that the additional history with cocaine reinforcement led to a 50% reduction in sensitively to price (α) and an increase in essential value with P_{max} increasing from 19 to 37 responses per unit reinforcement, dashed lines in Figure 12.10. Hence, the fundamental nature of addiction may be defined as a shift in the essential value of a commodity resulting from increased experience with the effects of the reinforcer.

If addiction can be defined as an increase in the essential value of a commodity and a decrease in elasticity of demand, then, perhaps, treatment for addiction can be defined as the reversal of that process—a reduction in essential value and an increase in elasticity of demand. Consistent with this expectation, Madden and Kalman (2010) reported that for individuals using bupropion to assist with smoking cessation, changes in elasticity (α from Equation 1) from the first to the second week of treatment were predictive of subsequent success in smoking cessation.

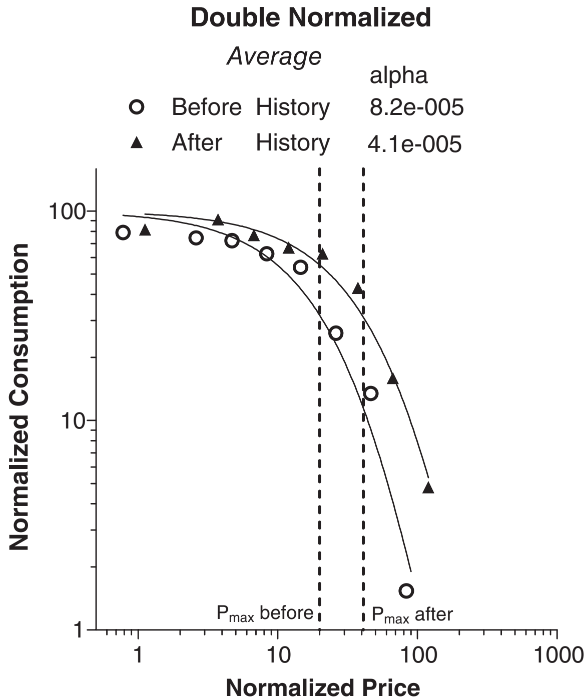

Figure 12.10 For the mean of a group of rodents, consumption of cocaine infusions as a function of increasing fixed-ratio schedule before (open circles) and after an extended history of exposure to cocaine (filled triagles), in log-log coordinates. The shift in P_{max} is shown as the two vertical dashed lines (Hursh & Roma, 2013).

Demand Elasticity in Open and Closed Economies

The literature on demand curves contains examples of situations that span a range of research paradigms, from non-human primates working in an environment with restricted access to alternative drug and non-drug reinforcers, to humans in a laboratory setting with limited access to alternative reinforcers during the period of the experimental session, to humans in a more clinical setting with unrestricted access to alternative reinforcers. As pointed out above (Hursh, 1980, 1984,1993), conditions that permit the reinforcer under study to be consumed outside the experimental setting are called *open economies* and demand curves are generally more elastic compared to conditions that restrict access to the experimental setting, *closed economies,* (see Hursh, 1991, Figures 13 and 14). For this reason, one would expect that the demand curves obtained in non-human primate studies *using closed economies* would be generally less elastic than those found in human studies with less restricted access or *open economies.* Nevertheless, *relative changes in elasticity* with changes in the availability of alternative reinforcers or resulting from pharmacotherapy should generalize across these research paradigms.

To illustrate the influence of contextual variables on elasticity, Spiga (personal communication) reported differences in the elasticity of demand for methadone in

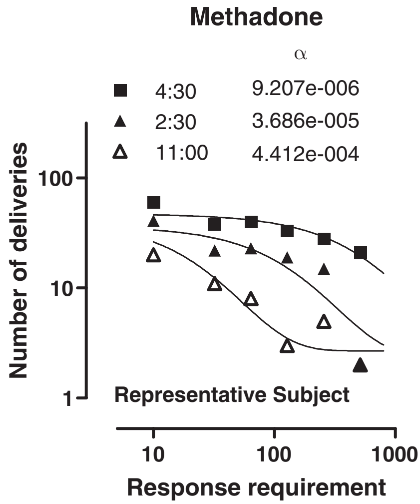

Figure 12.11 Methadone consumption by a human subject working for small deliveries of methadone under a series of fixed-ratio schedules arranged in separate sessions. The experiment was run at about 9 a.m. and unearned methadone was provided later at 11 a.m., 2:30 p.m. or 4:30 p.m. The number of earned doses by a representative subject are shown for the three times to the remaining dose.

human subjects working for methadone doses in morning sessions that occurred at about 9 a.m. The total daily dose of methadone for each subject was constant and any unearned methadone was provided later in the day, hence an open economy. However, the time to that second methadone dose was systematically varied, as shown in Figure 12.11 for a representative subject. When the second dose occurred at 11 a.m., α was large—consumption was quite sensitive to price; when it was provided in the afternoon at 2:30 or 4:30 p.m., the α parameter of the demand curve systematically declined to a level several orders of magnitude smaller. This illustrates that there is a temporal dimension to substitution; parallel to the concept of delay of reinforcement, delayed substitutes have reduced influence on demand elasticity relative to substitutes that are proximal in time (Hursh, 1991).

The difference between inpatient and outpatient treatment for addictive behavior is an obvious parallel to the distinction between closed and open economies, respectively. Patients who undergo drug detoxification, for example, in an inpatient clinic frequently fail to maintain abstinence when they return to their community and undergo outpatient treatment (Wikler, 1977, 1980). It is safe to say that detoxification does not "cure" addiction (see Koob & Le Moal, 2001; McLellan, Lewis, O'Brien, & Kleber, 2000). In part, this may be due to long lasting behavioral conditioning: Cues in the client's neighborhood elicit conditioned drug effects. This explains the subjective sensations reported by the subject and, perhaps, the initial attraction to the prior drug-taking pattern. However, the ultimate breakdown in abstinence that often occurs during outpatient treatment may simply be a reflection of the unfavorable economic conditions that skew preference toward the illicit commodity: higher reinforcing value, greater convenience of use (economies of time and distance), and strong collateral social reinforcement. Yet, outpatient treatment is a necessary step in the treatment or rehabilitation process; successful progress will depend on a realization that outpatient treatment is an open economy in which the benefits of treatment are economic goods evaluated in a competitive market. Innovations that improve the economic utility and reduce the psychological costs of therapy will serve to swing more clients toward compliance with the outpatient protocol. This generalization is applicable for a range of outpatient programs including treatment for drug and alcohol abuse, smoking, and obesity.

Therapy and Demand Interactions

The concepts of substitution and complementarity provide some insights into important limitations of individual therapy programs for the control or elimination of behaviors in excess in individual clients. Within a behavioral framework, one can conceptualize the therapeutic situation as one in which the therapist or the clinic attempts to shape new behavior under the control of acceptable reinforcers that compete with and reduce the occurrence of behavior to obtain unhealthy commodities, be it illicit drugs, alcohol, cigarettes, or excessive amounts of food. Thus, the reinforcers arranged by the therapeutic process interact with those from the target commodity (see Carroll, 1993; Thompson, Koerner, & Grabowski, 1984). For example, when monkeys were allowed to work for a sweet saccharin solution concurrently with consumption of PCP, elasticity of demand for PCP is increased and P_{max} moved to the left; however, considerable amounts of PCP were still consumed despite the presence of a competing reinforcer (Carroll, 1993).

The effectiveness of the competition between a drug reinforcer, for example, and other reinforcers will depend, at least in part, on several economic factors: the amount of direct substitution between the two sources of reinforcement, the availability of desirable complements to the therapeutic reinforcers that will maximize their effectiveness, and the amount of direct competition that exists between the two sources of reinforcement, i.e. does performance for one preclude or prevent reinforcement from the other (Greenwald, 2010). These factors can be illustrated by considering the effectiveness of methadone therapy for users of heroin.

Agonist Therapy

Methadone is an imperfect substitute for heroin; it is an opiate agonist and has many of the psychoactive properties of heroin and morphine. It is explicitly formulated so that an oral dose will prevent opiate withdrawal but will not produce a pronounced euphoria or "high." It substitutes for heroin to prevent withdrawal symptoms, the aversive consequences of non-drug use, but does not substitute for the immediate positive reinforcing consequences of euphoria. One could predict, then, that even if a large price differential existed between the two commodities, some heroin would still be purchased from illicit sources for its unique reinforcing features (see Stitzer, Grabowski, & Henningfield, 1984). A recent study has demonstrated that the exponential demand model may be used to explore the effects of agonists on the abuse liability of opiates (Banks, Roma, Folk, Rice, & Negus, 2011).

In addition, heroin is often consumed as part of a social ritual and these social events serve as complements to the primary reinforcing consequences of the drug (Matto, 2004). To the extent that the substitute, methadone, must be consumed in a clinical, non-social environment, its value will be diminished as an adequate substitute for heroin because it is not accompanied by important complementary social reinforcers (see Hunt, Lipton, Goldsmith, & Strug, 1984).

Antagonist Therapy

The use of methadone as a treatment for heroin is an example of the use of an agonist to substitute for the drug of abuse and drive up elasticity of demand. An alternative approach is to provide a drug therapy that is a specific antagonist for the drug of abuse; the antagonist binds to the neurochemical receptor and blocks the action of the drug without itself producing a psychoactive effect. A common antagonist for opiate drugs is naltrexone or naloxone; it is used in emergency rooms to rapidly block the action of opiates in patients that 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 has been tested in a study reported by Harrigan and Downs (1978). Monkeys worked for morphine under a series of increasing unit prices for morphine, arranged by decreasing the morphine dose per reinforcer. Morphine self-administration was studied either alone or when combined with one of three doses of intravenous doses of naltrexone. This yielded four separate consumption curves. Generally, the level of consumption of morphine at the lowest unit price *increased* in direct relation to the dose of naltrexone and sensitivity to the effects of increasing the unit price also increased with the dose of naltrexone. This apparently complicated effect of naltrexone can be resolved by examining exponential demand for morphine alone and in combination with naltrexone. Fitting exponential demand revealed that sensitivity to price (α) was unchanged but rather, there was an upward shift in Q_0 such that the demand curves with naltrexone were uniformly shifted to the right to higher effective prices considering the larger baseline levels of consumption required to reach satiation. To state it another way, naltrexone did not change the essential value of morphine but did lower the potency of each morphine infusion and raised the effective price of the drug.

At first, one might conclude that this indicates that antagonist therapy has no utility for the treatment of opiate "drug seeking" since it does not alter sensitivity to environmental price variables. In fact, this is not precisely true. The effect of naltrexone was to reduce the functional potency of the morphine. This had the effect of *increasing* the functional cost of morphine under each environmental cost, i.e. unit dose of morphine. Hence, increases in naltrexone moved the demand curve to the right and to lower daily levels of consumption. A sufficiently high dose of naltrexone would virtually eliminate any reinforcing value of morphine and, consequently, would move the functional price sufficiently far to the right that all consumption would cease under all levels of environmental cost. In effect, the morphine would be rendered ineffective as a reinforcer and the cost-benefit ratio for expending any effort to obtain it would approach infinity. This would occur, not because the fundamental demand for morphine was changed, but because the functional potency of morphine as a reinforcer was changed.

The clinical value of antagonist therapy is complicated by several considerations. As indicated above, the initial effect of an antagonist when the environmental price is low and the dose of the antagonist is insufficient to eliminate drug reinforcement is an increase in the total number of injections per day (increase in Q_0). This increase is motivated by the need to compensate for the functional decrease in the potency of the drug of abuse that brings with it several undesirable side effects. First, the number of doses of the drug required per day increases, and this potentially increases the need for funds to obtain the drug and to engage in illegal activities to raise the funds. Second, it increases the revenues to the drug suppliers. Third, for self-injected drugs, it may increase the use of dirty needles and increases the risk of needle transmitted diseases such as HIV/AIDS. But the primary challenge for any antagonist therapy is that it requires that the subject voluntarily administer a drug that will drive up the functional cost of another reinforcer. Ordinarily, consumers choose to minimize cost so such a choice would have to be compensated by a correlated increase in benefit from other sources of reinforcement, such as the retention of a well-paying job by a physician addicted to morphine. For many drug users, however, such alternatives may not be available unless provided by the therapeutic process itself.

From Science to Public Policy

In the previous sections, I discussed the factors that serve to control the choices of a person to work for and consume drugs of various sorts. Many other policy decisions relate to similar choices for other commodities. For example, in the arena of environmental and energy policy, tax incentives and rebates are often provided to encourage citizens to purchase more fuel-efficient cars, to increase the insulating properties of homes, or to adopt alternative energy sources for home electricity. The power of such policies depends on the price sensitivity of the commodities at issue. When attempting to encourage alternative energy choices, high price sensitivity is a virtue because it suggests that small reductions in price (using rebates, for example) will have relatively large effects on consumption. When attempting to discourage wasteful use of resources, such as taxes on the use of paper bags, high price sensitivity is again a virtue because a small cost, such as 5 cents per bag, might be expected to have a relatively powerful effect on consumption. When attempting to reduce drug use, provision of medically administered alternatives like methadone are expected to increase price sensitivity of demand for substitutable illicit alternatives, resulting in an overall decrease in consumption of the illicit commodity in favor of the lower cost (and legal) medical alternative.

When formulating such policies, it is important to understand the demand elasticities of the commodities at issue; in effect, it is important to be able to establish the value of α for the various alternatives. This requirement presents a challenge because often there are not naturalistic data available to allow for the mapping of the basic demand curve. When naturalistic data are available based on market fluctuations or differences in supply (and price) across different geographic locations, the range of prices is often very limited. This makes it difficult to precisely map the demand curve

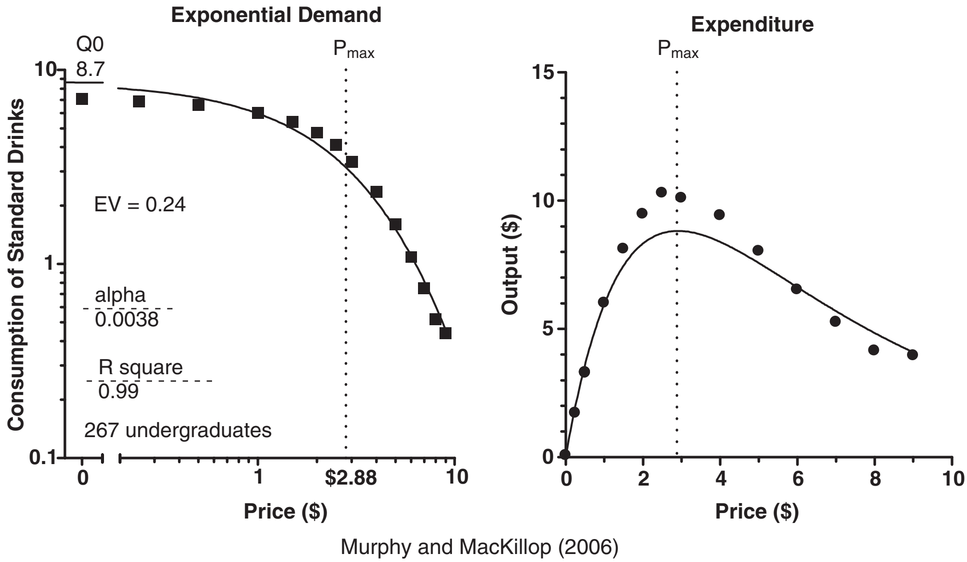

Figure 12.12 The reported consumption of standard alcoholic drinks as a function of the cost of each drink from a group of 267 college undergraduates responding to a set of questions about hypothetical alcohol consumption (from Murphy & MacKillop, 2006).

and determine the value of α. Along with other economics-oriented approaches (e.g., Roddy, Steinmiller, & Greenwald, 2011), recent experiments have been conducted using "hypothetical" demand curves constructed by asking subjects to indicate the levels of consumption that they would adopt if confronted with different prices for the commodity in question. Typically such experiments involve describing a scenario that defines the purchase setting, the commodity offered for sale, the availability of other possible alternatives and their prices, limits on when the commodities can be consumed to prevent hypothetical savings or reselling, limits on how much money the subject has to spend, and other possible environmental constraints. These experiments have shown that such hypothetical demand curves (1) have a consistent shape well described by the exponential demand equation and (2) have values of α that vary with hypothetical contextual variables.

Murphy and MacKillop (2006) surveyed alcohol consumption as a function of price in 267 undergraduate students. Figure 12.12 is the resulting demand curve (left panel) and response output function (right panel). The line through the hypothetical consumption curve is the best fitting exponential demand curve, and accounted for 99% of the variance in consumption. The expenditure function also was well described by the function, and the point of maximum consumption (P_{max}) coincided closely with the maximum of the exponentially derived output function. While we have no independent way to assess the true levels of consumption of alcohol in these students, the systematic relationship obtained using the hypothetical method is encouraging.

One way to assess the usefulness of such functions is to determine if they vary in a rational way with other ecologically valid variables. To that end, Murphy and

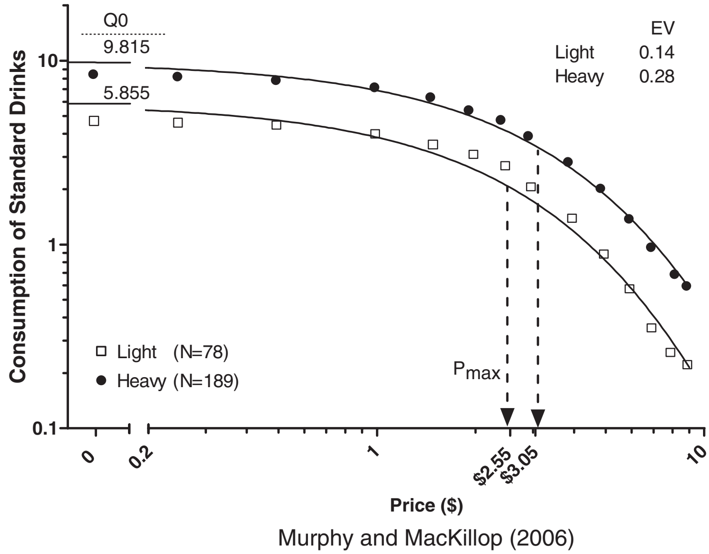

Figure 12.13 The reported consumption of standard alcoholic drinks as a function of the cost of each drink from two groups of college undergraduates, one group self-reporting light consumption (n = 78), and one group reporting heavy consumption (n = 189). Subjects responded to a set of questions about hypothetical alcohol consumption (from Murphy & MacKillop, 2006).

MacKillop (2006) related the demand curves in these students to their reported overall use of alcohol. They divided the 267 students into two groups defined as light and heavy alcohol users. The two resulting demand curves (Figure 12.13) differed from each other in both Q_0 and α. Heavy drinkers had higher levels of consumption, as might be expected from their self-assessment of overall use, but they also showed less sensitivity to alcohol price, with an α value about half that of light drinkers. In a similar study, MacKillop et al., (2008) reported that minimal users of nicotine products had price sensitivity (α) that was five times higher than that reported by those with moderate nicotine use.

These findings suggest that hypothetical demand curves may be used as a tool for demand curve assessment to inform public policy that will use taxes to increase prices to discourage certain behaviors, or use incentives and rebates to encourage other behaviors (see Bidwell, Mackillop, Murphy, Tidey, & Colby, 2012; MacKillop, Few, Murphy, Wier, Acker, Murphy, Stojek, Carrigan, & Chaloupka, 2012). Such research will provide two important bits of information. First, it will help define the overall shape of the underlying demand curves and the associated α values. Second, it will help define where the current prevailing price is relative to P_{max}, i.e., is demand elasticity in the vicinity of the current price elastic or inelastic. This will lead to directly verifiable predictions of the policy's (price increase or decrease) effect size on resulting consumption.

A recent study reported by Roma et al. (2013) demonstrates that with a relatively small number of subjects (8), meaningful hypothetical demand curves can be obtained that differentiate between a range of commodities in important ways. The subjects in this study were all former opiate (heroin) users enrolled in a methadone treatment program. All reported experience using prescription opiate pills, such as OxyContin, and manipulating them, for example, crushing them to be inhaled or dissolved for injection. They were asked to estimate the level of consumption of a range of commodities across a wide range of prices, including several forms of opiate pills. The commodities were: standard opiate pills that could be crushed, opiate pills that could not be crushed and could only be swallowed (tamper resistant formulation), alcoholic drinks, cigarettes (nicotine), and a non-drug control, chicken nuggets or wings. Figure 12.14 shows the results for all five commodities. Shown are the demand curves and beneath the curves are two bar graphs, one showing maximum consumption at zero price, and one showing the *essential value* (Equation 2) of each commodity. Most importantly, the standard opiate pills that could be crushed had the highest essential value and the tamper resistant opiate pills that had to be swallowed had significantly lower essential value. Oral opiate pills had a higher maximum consumption than the standard pills at the lowest price, presumably because the subjects would have taken more of them to compensate for the oral route of administration. Nevertheless, consumption of the oral opiate pills was more sensitive to price and declined more quickly across increasing prices, indicating that a tamper resistant formulation would reduce the essential value and illicit demand for prescription opiates pills in the street market.

On the other end of the continuum, in these same subjects, chicken would have been purchased at about the same level when free as opiate pills but, as we would expect, consumption was much more sensitive to price so that the essential value of chicken was about one-seventh that of standard opiate pills. Between these two extremes were alcohol and cigarettes. About as many cigarettes would be purchased as opiate pills when free, but consumption declined more quickly with increasing price so that essential value was about one-fourth that of the standard opiate pills. Alcohol would be purchased at a level lower than cigarettes but had about the same essential value. These data taken together illustrate how hypothetical demand can be used to assess both the level of consumption and the abuse potential of a range of commodities and can be used to test the value of tamper resistant formulations as a deterrent to illicit prescription drug use.

The previous charts illustrate how hypothetical demand can be used to compare consumption patterns across subjects and commodities. It is also important to establish that hypothetical demand can reflect the context of alternatives and disincentives that might alter demand. This is important because some policy initiatives impose non-monetary costs. For example, consider a policy that would encourage the use of an alternative ethanol-based fuel for automobiles. Even if the price of the fuel were equivalent to the price of regular gasoline, other costs might have a dramatic impact on utilization, such as the travel time and distance to the alternative fuel station, the potential to travel to a location that does not have such fuel, and a possible reduction in fuel mileage necessitating increased frequency of refueling. If the vehicle would run on both kinds of fuel (i.e., if the two fuels were functionally substitutable), the much higher convenience of using the standard fuel might outweigh any environmental benefit. To combat this disincentive, the policy maker may have to provide counteracting incentives to the consumer, such as refueling rebates and tax incentives.

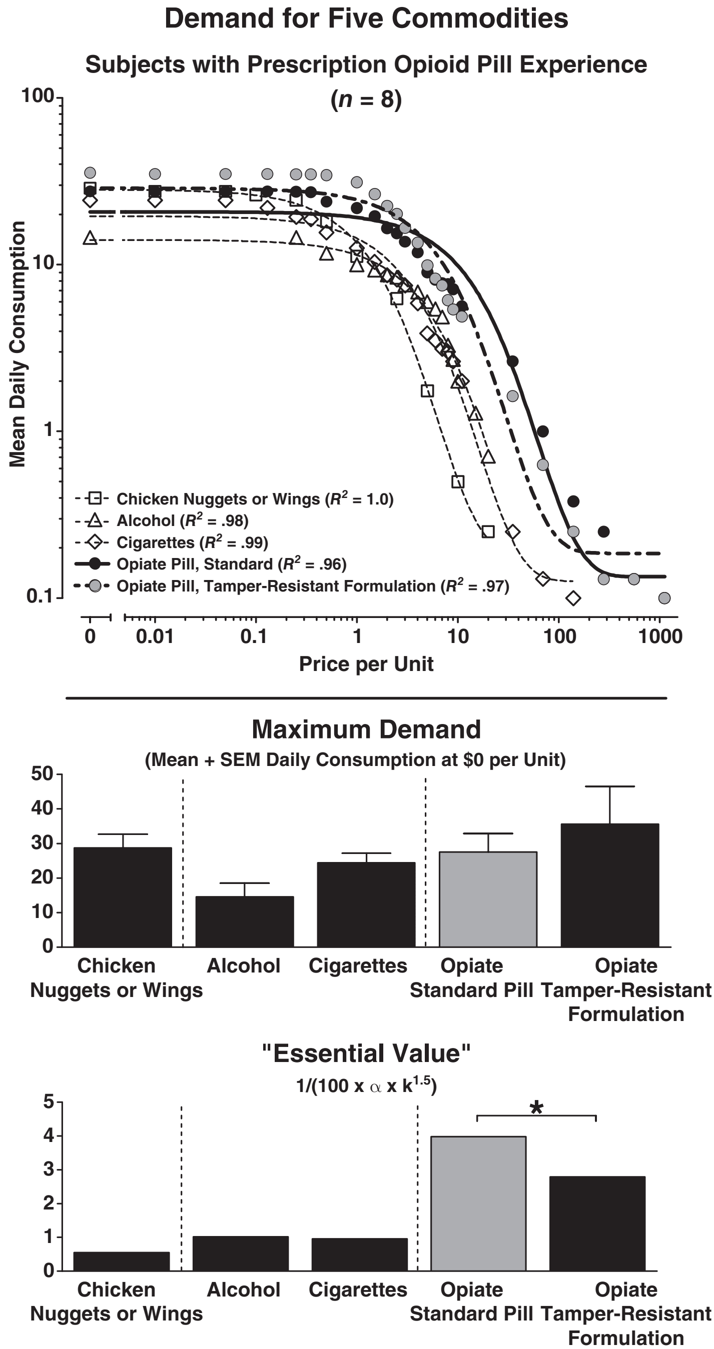

Figure 12.14 The reported consumption of five commodities as a function of the cost of each from former heroin users in methadone treatment (N = 8) chosen based on prior experience using opiates in pill form (from Roma et al., 2012). The top panel shows reported consumption as a function of price of five commodities; the bottom two panels show maximum reported consumption and essential value (Equation 2) for each commodity: chicken nuggets or wings, alcohol drinks, cigarettes, standard opiate pill, and tamper resistant opiate pill (Roma et al., 2013).

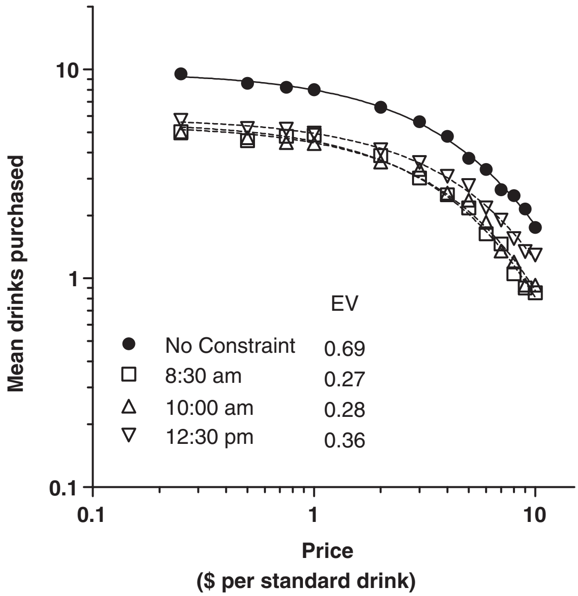

Figure 12.15 The reported consumption of standard alcoholic drinks as a function of the cost of each drink from college undergraduates (N = 164) randomly assigned to one of three hypothetical academic constraints (academic classes scheduled at 8:30 a.m., 10:00 a.m., and 12:30 p.m.) or a control condition: no constraint. The curves fit to the data are from the exponential demand model and the values of EV (Equation 2) are shown for each condition (from Gentile et al., 2012).

In addition, the policy maker may need to take steps to reduce the disincentives, such as encouraging producers to increase availability of the alternative fuel. But the question ultimately becomes one of how much compensation is required to have a beneficial impact on alternative fuel use. The method of hypothetical demand curves provides an empirical approach for evaluating the impact of these incentives on expected consumption, providing an empirical basis for a rational cost-benefit analysis of the proposed policy. While the results in Figure 12.14 are encouraging, future research should seek to further establish the validity of hypothetical demand curves as predictors of actual consumption in the natural economy.

To illustrate how disincentives and contextual variables may be evaluated with hypothetical demand curves, Gentile, Librizzi, and Martinetti (2012) used an alcohol purchase task similar to that used by Murphy and MacKillop (2006) to assess the effects of academic constraints (next-day class time and next-day class requirement) on alcohol demand among college students. The three "academic constraint" conditions involved scenarios that included a next-day class that differed by scheduled time (8:30 a.m., 10:00 a.m., or 12:30 p.m.), or a control condition (no next-day class). Exponential demand analyses revealed that participants in all three of the academic constraint conditions reported fewer drinks consumed and displayed lower "essential value" of alcohol, or greater sensitivity to price increases, compared with the no-constraint control. The results are plotted in Figure 12.15 and show excellent fits to the exponential demand model and progressively decreasing sensitivity to price

(α) as the delay to the next-day class increased, with the lowest sensitivity occurring when no class was scheduled (no constraint).

These results confirm that hypothetical demand curves are sensitive to modulating variables such as the potential disincentive of attending an academic class after the consumption of the commodity, here alcoholic drinks. From a policy perspective, this opens the possibility of investigating a range of public policy variables that might involve the combination of price and contextual incentives and disincentives.

Conclusions

At its heart, behavioral economics attempts to apply concepts developed by microeconomists studying human economic markets, such as consumer demand and labor supply theories, to understand how the behavior of individual organisms is maintained by various commodities. This theoretical framework has proven useful for understanding the environmental control of overall levels of behavior for a variety of reinforcing "commodities" in the laboratory, including self-administered drugs in animals and humans. One of the most important contributions of behavioral economics has been to direct attention to total daily consumption as a primary dependent measure. Changes in consumption in relation to the prevailing price—elasticity of demand—is a key indicator of consumer motivation and serves to define the "essential value" of commodities. Essential value, then, is a useful metric to categorize differences between commodities, differences between individuals toward similar commodities, and differences in the value of commodities across different contexts of available alternatives and disincentives (see Oliveira-Castro, Foxall, Yan, & Wells, 2011). The overarching value of this framework is an ability to understand behavioral tendencies that are quantitatively precise at the level of individual organisms and scalable to understanding factors that control the motivation of many individuals within an entire community. Behavioral economics makes the science of behavior a practical evidentiary foundation for decision-making and is a common language for translational research in support of empirical public policy (Magoon & Hursh, 2011).

Notes

1 The exact value of P_{max} varies slightly with the value of k so that a closer approximation is achieved by correcting eq (2) with an adjustment for the value of k: $P_{max} = m/(Q_0 \cdot \alpha \cdot k^{1.5})$, where $m = 0.083k + 0.65$.

2 If both the prices of commodity B and commodity A are changing, then Equation 3 can be expanded by replacing the $\log(Q_{alone})$ term for commodity B consumption at a fixed price with Equation 1 for commodity B consumption with variable 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.

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