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Behavioral Economics and the Analysis of Consumption and Choice

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Behavioral economics (BE) in psychology focuses on the application of traditional microeconomics concepts to the study of behavior, particularly the cross-species analysis of consumption broadly defined and choice. Here, we review key concepts such as demand, substitution, and complementarity within a behavioral psychology framework, novel behavioral economics analysis techniques for quantifying demand elasticity and patterns of choice behaviors, and broader implications for organizational decision-making and empirical public policy.
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INTRODUCTION

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 commodities in conventional economic contexts. Indeed, the blending of behavioral principles with micro-economic theory has been a fruitful area of research (Hursh, 1980; Kagel, *et al*., 1975; Kahneman *et al*., 1982; Lea, 1978; Rachlin *et al*., 1976; Rachlin and Laibson, 1997; Thaler and Mullainathan, 2008) and provides a scalable framework for extending principles derived from laboratory studies to an understanding of consumer choices, on a continuum from the individual through that observed in whole communities. Practical application of these methods also paves the way for empirical research to test the implications of public policies that seek to influence the choices of people in society (Hursh and Roma, 2013; Magoon and Hursh, 2011).

There are several points of convergence between economics and behavioral psychology. One is a common interest in the value of goods, defined as 'reinforcers' by the behaviorist because they strengthen the likelihood of the behaviors producing them 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 application 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).

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Concepts of behavioral economics have proven useful for understanding the environmental control of overall levels of behavior for a variety of commodities in closed systems (Lea and Roper, 1977; Lea, 1978; Hursh, 1984; Rashotte and Henderson, 1988; Bickel *et al*., 1990, 1991, 1997; Foltin, 1992) and the factors that control the allocation of behavioral resources among available reinforcers (Hursh, 1980, 1984; Hursh and 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 (Rachlin *et al*., 1976; Watson and Holman, 1977; Lea, 1978; Allison *et al*., 1979; Staddon, 1979; Allison, 1983; see Kagel *et al*., 1995 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, and differentiation. These experiments have directed our attention to new phenomena previously ignored and new functional relations previously unnamed. In this review, behavioral economics is applied to the analysis of consumption of various reinforcers and the responding that produces that consumption. We provide some basic groundwork that will serve as a primer for understanding behavioral economic concepts that could be applied to a range of behaviors in the laboratory and clinical settings, and we will illustrate extensions to human behavior that could advance our understanding of choice behavior and empirically inform decisions at the organizational and public policy levels.

VALUE OF REINFORCERS

One of the most important contributions of behavioral economics in psychology 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 commodities. 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 to eliminate it as 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); that is, the situation is not a closed system with regard to sources of the reinforcers when the commodity is offered for free outside the experiment. 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 commodity 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 (Hursh, 1978, 1984; Hursh and Natelson, 1981; Lucas, 1981; Collier, 1983; Collier *et al*., 1986; Hursh *et al*., 1988; Raslear *et al*., 1988; LaFiette and Fantino, 1989; Hall and Lattal, 1990; Bauman, 1991; Foster *et al*., 1997; Zeiler, 1999; Roane *et al*., 2005).

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 or 'price' (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 *et al*., 1979, 1980; Hursh and Winger, 1995). It is important that when comparing drug reinforced behavior to behavior reinforced by another commodity, such as food, that a closed economy be arranged for that reinforcer as well. The behavioral

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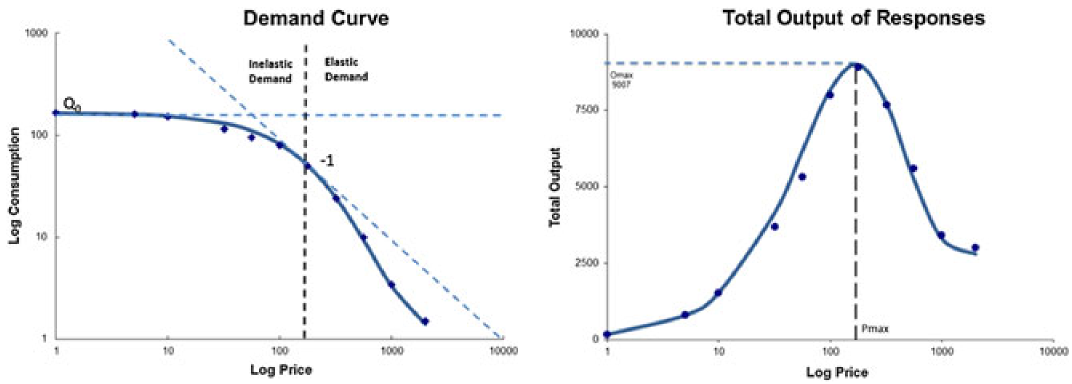

Figure 1. Left panel: diagrammatic demand curve showing the usual shape and increasing elasticity across the demand curve. The vertical line marks the point of unit elasticity (slope = −1), which is the transition from inelastic to elastic demand. The level of demand is denoted as the y-intercept or 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}.

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, as illustrated in Figure 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 decreases at a slower rate than the price increases, we define that as 'inelastic demand'. For this to occur, total responding or expenditures must increase as cost increases (Figure 1, right panel). For example, when the price of gasoline increased threefold during the 1970s from 33 cents a gallon to over $1 a gallon, consumption decreased by only 10% (Nicol, 2003); similar patterns have also been observed more recently (Reed *et al*., 2013). These are powerful examples 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.

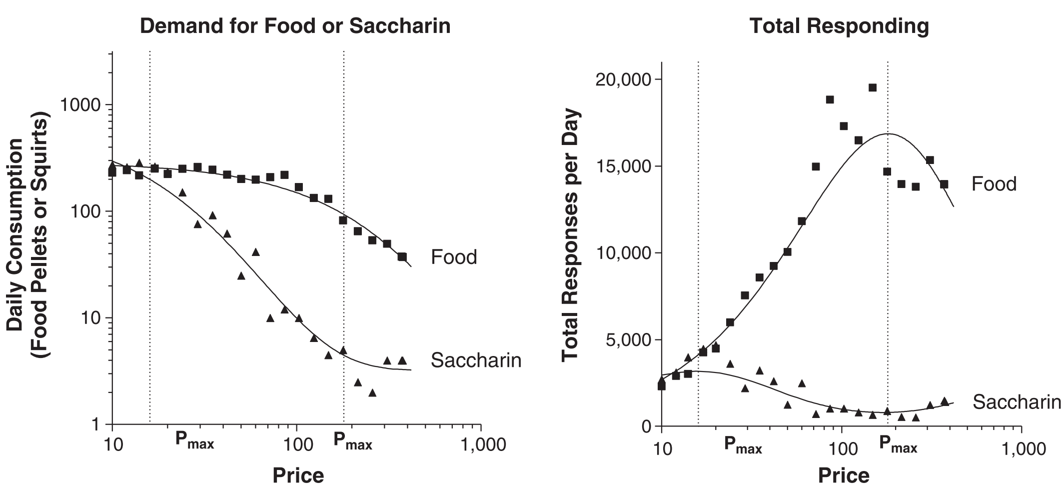

Figure 2. Left panel: two demand curves by rhesus monkeys working for either food (squares) or saccharin sweetened water (triangles). The functions show the total number of reinforcers earned (consumption) each day under a series of fixed-ratio (FR) schedules (prices) that ranged from FR 10 to FR 372. 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 and Roma, 2013).

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Demand for such goods is 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 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 unit price of each commodity (food or saccharin) was gradually increased from 10 responses 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 is not binary but rather 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 demands and coincides with the peak of the response rate functions ($P_{\max}$) shown in the right panel of Figure 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.

Measuring Demand

In order to use elasticity of demand as a basic yardstick for assessing value and '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) and Hursh *et al*. (1988) have proposed that consumption can 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, for example, the total number of food deliveries, drinks of water, or injections of a drug. 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 in the laboratory is normally specified as the value of the fixed-ratio (FR) schedule of reinforcement. In animal studies, this equates to the number of physical behavioral responses, such as a lever press or button push, required per unit of the reinforcer. For human subjects, it may also 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 cost of each reinforcer. In some experiments, the cost may be the amount of time spent working for the reinforcer, which would be the value of the fixed-interval schedule of reinforcement (Bauman, 1991).

As depicted in Figure 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, in an equation known as the Exponential Model of Demand (Hursh and Silberberg, 2008)

$$\log Q = \log Q_0 + k\left(e^{-\alpha\cdot(Q0\cdot C)} - 1\right). \quad (1)$$

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 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. The rate of change in demand elasticity, when k is constant is determined by the rate constant, α. The value of α gauges to the sensitivity of consumption to changes in cost and is inversely proportional to the *essential value* (EV) of the reinforcer, the theoretically constant reinforcing value of the commodity regardless of unit size.

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 maximum demand 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

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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) separates cost factors from that component of elasticity due entirely to differences in EV as reflected in the α term. 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 $Q_0 \times C$.

Sensitivity to price is specified by α and is inversely proportional to 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 (Hursh, 2014) is given in Equation (2)

$$\mathrm{EV} = 1/\left(100 \bullet \alpha \bullet \mathrm{k}^{1.5}\right). \tag{2}$$

This definition of value may be used to scale EV for different reinforcers across a range of experiments. The value of EV in Equation (2) is linearly related to the price at which demand elasticity is -1, and overall responding is maximal, that is, the price point we call $P_{\max}$. This estimate of $P_{\max}$ 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 ($C \times Q_0/100$). The exact value of $P_{\max}$ expressed in units of C varies slightly with the value of k so that a nearly exact estimate of $P_{\max}$ is achieved by replacing the constant of 100 in Equation (2) with the value of Q_0 and adjusting for the value of k:

$$P_{\max} = \mathrm{m}/\left(Q_0 \bullet \alpha \bullet \mathrm{k}^{1.5}\right), \text{ where} \quad \mathrm{m} = 0.084\mathrm{k} + 0.65. \tag{3}$$

Comparing Reinforcers in Terms of Demand

An important feature of the Exponential Model and derivate metrics thereof is that it provides a credible standardized platform for direct quantitative comparisons of qualitatively different commodities. For example, the demand for three drugs self-administrated by monkeys was assessed by Winger *et al.* (2002), specifically three anesthetic-class drugs that differ systematically in time of onset to peak drug effect. Ketamine, phencyclidine, and dizocilpine were measured to have times to peak visible physiological effects of 1, 10, and 32 min, respectively. The Exponential Model permitted a direct comparison of elasticity of demand for these three drugs, as shown in Figure 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 maximum demand Q_0 parameter, thereby rendering sensitivity to price (α) constant across doses of the same drug. Second, Figure 3 shows that EV was

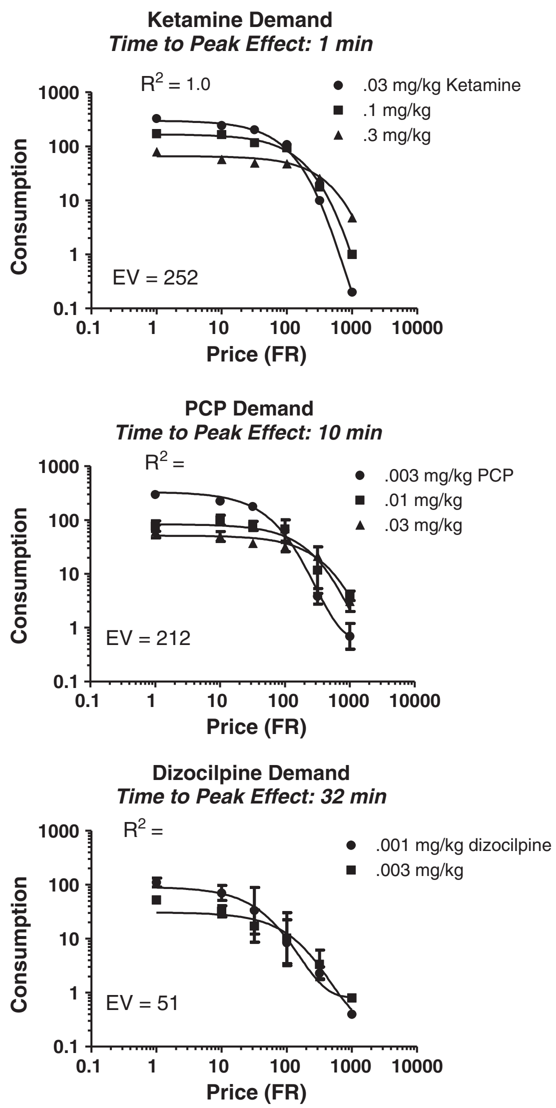

Figure 3. Demand curves (Equation (1)) fit to average consumption of three drugs self-administered by rhesus monkeys (Winger *et al.*, 2002). The drugs were ketamine, phencyclidine (PCP), and dizocilpine. Also shown are the essential values for each drug (Equation (2)). EV, essential value; FR, fixed-ratio.

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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 EV. Figure 3 illustrates the utility of using demand curve analysis and exponential demand to scale psychoactive drugs for EV and abuse liability. Similarly, Roma *et al*. (2013) recently reported pilot data of demand for a range of drug and non-drug commodities in a hypothetical purchase task (HPT) study, the results of which suggested a direct relationship between EV and the abuse potential of drugs. Specifically, participants with a history of opiate pill use exhibited higher EVs for opiate drugs than alcohol, cigarettes, and food, but abuse-deterrent/tamper-resistant pills were still lower than standard pills (Hursh, 2014). Put another way, drugs with comparatively high sensitivity to price (large values of α and low EV) 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 EV and $P_{\max}$. That relationship appears to hold for the three drugs reported in Figure 3. The EVs (Equation (2)) were 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 4. In other words, the value of these drugs as a reinforcer and the sensitivity of consumption to the prevailing price were 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 and Fantino, 1973; Tarpy and Sawabini, 1974; Mazur, 1985; Mazur *et al*., 1985; Grace *et al*., 1998; Woolverton and Anderson, 2006). In behavioral terms, EV is an inverse function of delay to 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 compounds, such as opiates for the treatment of pain.

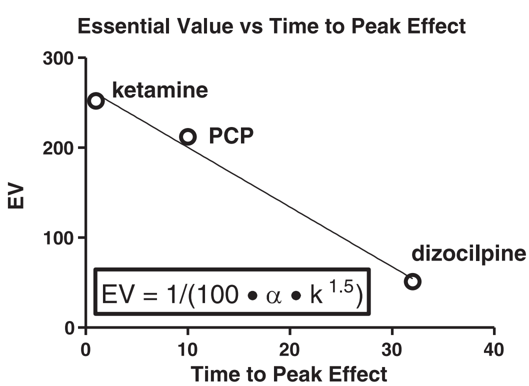

Figure 4. Essential value (EV) as a function of the average time to peak physiological effect of the drugs ketamine, phencyclidine (PCP), and dizocilpine.

FACTORS THAT ALTER DEMAND AND CHOICE

Elasticity of demand is not an inherent property of any reinforcer, but rather the product of an organism interacting with its environment, be it an animal in a laboratory experiment or a human consumer in the open marketplace. For example, one of the primary differences between open and closed economies is elasticity of demand. While demand for food in a closed economy is inelastic over a wide range of prices (Figure 2) where the subject controls its own intake and no supplemental food is provided, demand for 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 min after a 12-h work period for food at higher prices. The price of food in the work period was increased to assess demand (Figure 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 with demand for food when no low cost food was available, demand when an alternative source was available was much more elastic with an 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, as indicated by $P_{\max}$. Comparing Figure 5 with 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 2 and discussed earlier. 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

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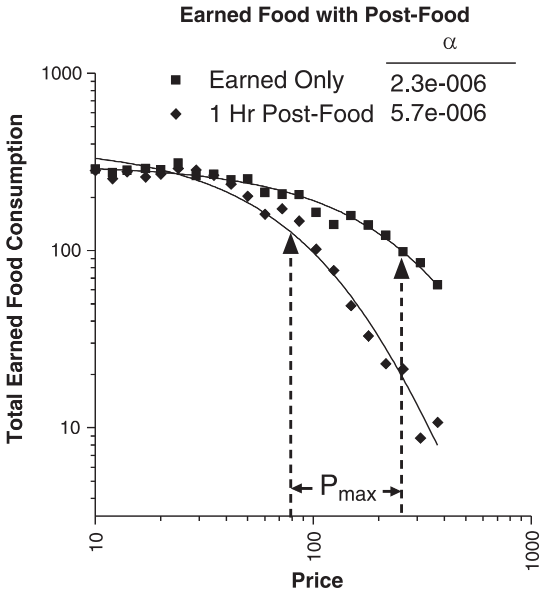

Figure 5. Two demand curves by a rhesus monkey for food during a 12-h work period, either with no other source of food (closed squares) or with a 1-h period of fixed-ratio (FR) 1 food reinforcement immediately following the work period (closed diamonds). Consumption is shown as a function of the FR schedule that ranged from FR 10 to FR 372 (Hursh, 1993).

with the environment. Within a behavioral economic framework, reinforcer interactions are classified into several categories, illustrated in Figure 6. If we think of commodities as collections of attributes, we can represent those attributes as a 'set' or circle in Figure 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 and McCarthy, 1988). When the two alternatives require a specific number of responses per reinforcer delivery, the subjects generally show exclusive preference for the least costly of the alternatives (Herrnstein, 1958; Herrnstein and Loveland, 1975). This situation is much like comparison shopping for identical items from different stores; all else being equal, the consumer will choose the store with the lowest price.

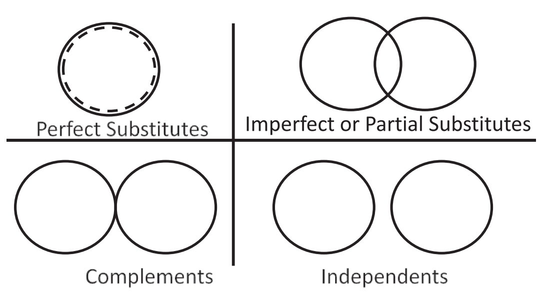

Figure 6. Diagram of four hypothetical forms of reinforcer interactions (see text for explanation).

Unless choosing between different stores for the same good, most choices are between commodities that are not perfect substitutes (Green and Freed, 1993, 1998). In the market place, the quality of goods is largely a subjective rating, and one goal of advertising is to distinguish one good from another by highlighting the special benefits of a particular alternative, which might justify a higher price. Yan, Doylen and Foxall (2012a, 2012b) have described variations in EV that depend on the qualitative attributes of each commodity. They define 'utility value' as the direct benefit or reward value from the good, and 'information value' as the symbolic or social impact of the goods, such as the status conferred by owning the good. Given these qualitative dimensions of consumer choice, understanding the interactions between prices for different commodities requires a classification scheme that goes beyond the simple case of choice between perfect substitutes. The other interactions depicted in Figure 6 are *imperfect substitutes*, *complements*, and *independent* reinforcers. Imperfect substitutes share many features, but each also poses unique features not contained in the other reinforcers. Complements are a special kind of reinforcer interaction in which the presence of the features of one reinforcer enhances the value of the features of the other reinforcers, that is, their individual values are 'connected'. Finally, independent reinforcers share no common functional properties, nor does the presence of one alters the value of the other; hence, the sets are disconnected.

Figure 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 8 (Spiga, unpublished). Using a procedure

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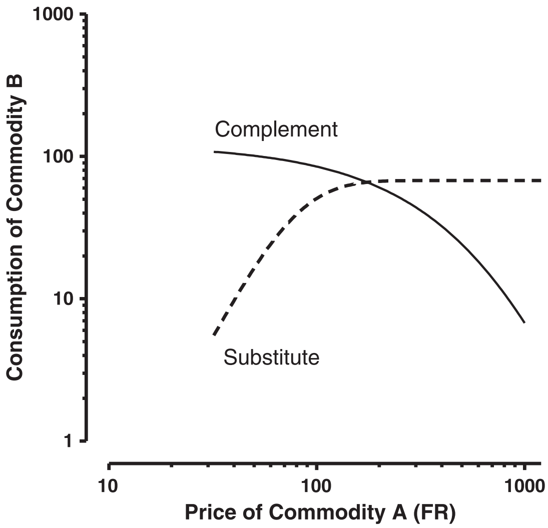

Figure 7. Diagram of hypothetical changes in consumption of commodity B as a function of the price of commodity A. The solid line indicates a complementary relation; the dashed line indicates a substitutable relation (Hursh and Roma, 2013). FR, fixed-ratio.

similar to that reported by Spiga *et al*. (2005), human subjects chose between the opiate drug methadone available after pressing one lever under an increasing series of FR prices. The other alternative was a different opiate, hydromorphone, available under a constant FR schedule. Even at the lowest price of methadone (FR 30), some hydromorphone was consumed; as the

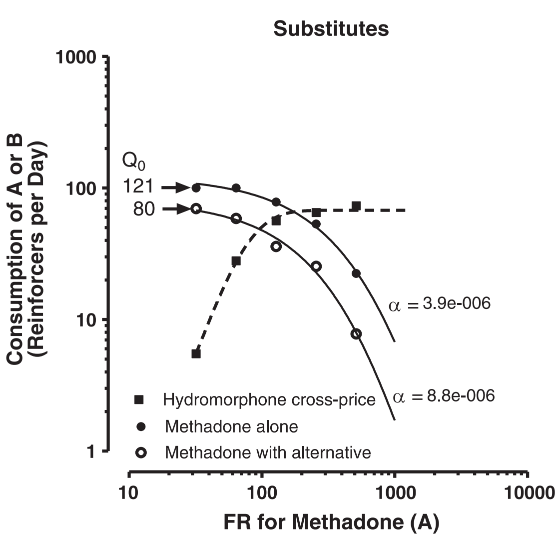

Figure 8. Mean daily consumption by human subjects of methadone (commodity A) and hydromorphone (commodity B) as a function of the unit price (fixed-ratio (FR) schedule) for methadone, in log-log coordinates (Spiga, unpublished).

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 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 primary drug of abuse. In this experimental model of the therapeutic process, methadone demand is like demand for an illicit drug, and the hydromorphone is like the drug therapy. Behavioral economics provides an approach to evaluate 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 earlier, 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 in Equation (1). Determining the demand for illicit drugs using actual patients can also take an indirect approach using HPT questionnaires (Roma *et al*., this issue). 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 applied to actual consumption curves (Hursh and 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 maximum demand (Q_0) and increase sensitivity to price (α).

Complementarity

Choice between two complements is illustrated in Figure 9 (Spiga, Wilson, and Martinetti, unpublished). The two alternatives here were ethanol drinks and cigarette puffs. In the right panel, ethanol drinks were

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offered at a constant price (commodity B), and the price of cigarette puffs (commodity A) was varied, either alone or concurrently with the ethanol. 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 alone or concurrently with cigarette puffs. As the price of the variable price commodity A increased, consumption of that commodity decreased and daily consumption of the fixed price alternative (B) also 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 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 underlying 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 earlier, demand curves are usually nonlinear, and elasticity increases with price. The Exponential Model of Demand in 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 Exponential Model represents the rate of change in elasticity of demand and is inversely related to the value of the commodity. However, the rate of change parameter, *a*, cannot be used to directly compare commodities across conditions or experiments unless the scaling factor, *k*, is constant. That requirement is impractical across different studies and may force the results from two experiments to be modeled using a single scaling factor that may not properly represent both sets of data. To avoid this methodological limitation, commodities can be compared using the EV expression in Equation (2), which controls for the scaling factor, *k*, which best fits the data. EV increases with the value of the commodity and is a robust way to compare the value of commodities across conditions and experiments. The second method for comparing commodities is closely related to EV and 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

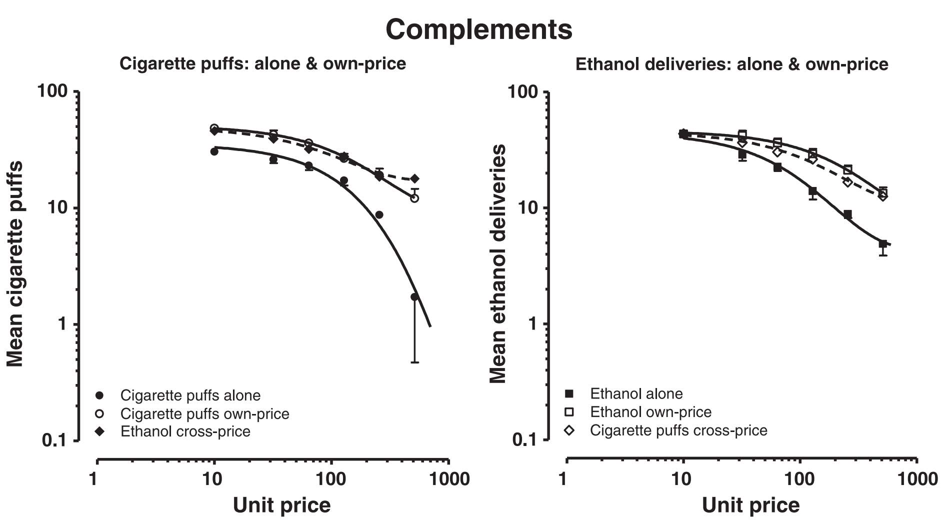

Figure 9. For human subjects, consumption of fixed price alternatives (commodity B, dashed lines) ethanol drinks (left filled diamond) or cigarette puffs (open diamond right) and the variable price alternative (commodity A) as a function of the fixed ratio for commodity A (open circle or open square) in log-log coordinates. Demand for cigarettes or ethanol drinks alone is shown as filled circles (left) or filled squares (right), respectively (Spiga, Wilson, and Martinetti, unpublished).

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common point of reference across conditions and studies using the expression in Equation (3). 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 (Figures 8 and 9). As noted earlier, if this function has positive slope, then the second commodity is termed a substitute for the first (Figure 8); if the slope is negative, then the second is termed a complement of the first (Figure 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 8 for hydromorphone (substitute for methadone) or in Figure 9 for ethanol and cigarettes (complements to each other)

$$Q_B = \log(Q_{alone}) + Ie^{-\beta \cdot C_A}, \quad (4)$$

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 8, the interaction term I was negative (−3), indicating a reciprocal or substitution relationship between consumptions of the two commodities; in Figure 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.[1]

To summarize, EV may be dramatically affected by the availability of alternative reinforcers. When substitutes are available, the EV 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 EV with imperfect substitutes and delayed alternatives producing more modest declines in EV. At the other end of the continuum, concurrently available complements increase the EV of a reinforcer. These reinforcer interactions are not traditionally incorporated into prominent models of decision-making such as Herrnstein's (1970) matching law, although extensions to qualitatively different commodities and to choices in the 'market place' have been described (Green and Rachlin, 1991; Herrnstein and Prelec, 1992).

FROM SCIENCE TO ORGANIZATIONAL DECISION-MAKING AND PUBLIC POLICY

In the prior sections, we discussed the factors that serve to control the choices of individuals to work or pay for and consume various commodities. 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 for opiate addiction 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 no 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 and determine the value of α. Along with other economics-oriented approaches (e.g., Roddy *et al.*, 2011), a growing literature is based on recent experiments that have been conducted using HPT questionnaires where demand curves are constructed by asking subjects to indicate the levels of consumption 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

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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 (i) have a consistent shape well described by the exponential demand equation and (ii) have values of α that vary with hypothetical contextual variables.

For example, Murphy and MacKillop (2006) surveyed alcohol consumption as a function of price in 267 undergraduate students. Figure 10 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 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 11) 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 (and thus lower EV) than that reported by those with moderate nicotine use.

These findings suggest that HPTs may be used as a tool for demand curve assessment to inform corporate decision-making and public policy. The decision-maker may consider using taxes to increase prices to discourage certain behaviors or using incentives, such as rebates, to encourage sales or other desirable behaviors (Bidwell *et al*., 2012; MacKillop *et al*., 2012). Hypothetical demand research will provide two important bits of information. First, it will help define the overall shape of the underlying demand curves and the associated EVs. Second, it will help define where the current prevailing price is relative to P_{max}, that is, whether demand elasticity in the vicinity of the current price is elastic or inelastic. This will lead to directly verifiable predictions of the effect of any organizational-level decision (price increase or decrease) on resulting consumption.

It is also important to establish that HPTs provide a means of assessing the effects of alternatives and disincentives on demand. This is important because some policy initiatives impose non-monetary costs. For

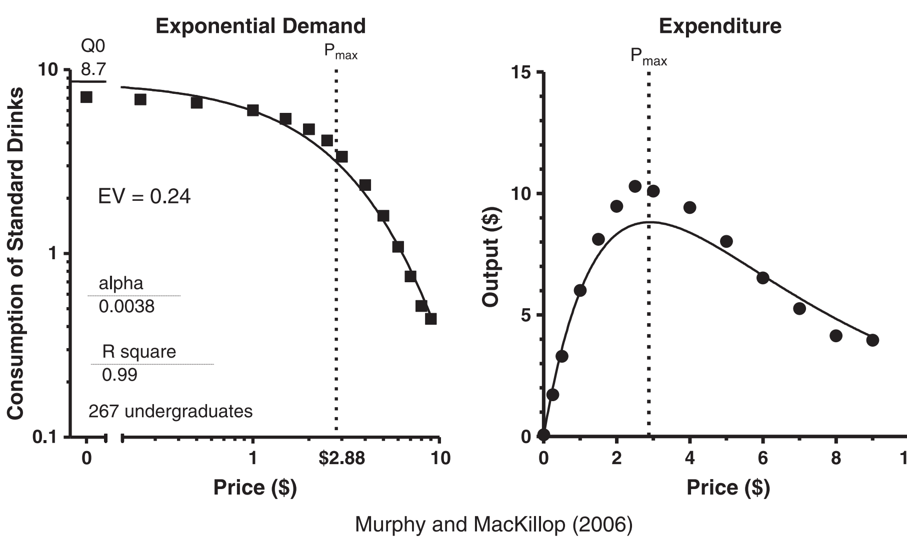

Figure 10. The reported consumption of standard alcoholic drinks as a function of the cost of each drink from a group of 267 college undergraduates responding to a set of questions about hypothetical alcohol consumption (from Murphy and MacKillop, 2006).

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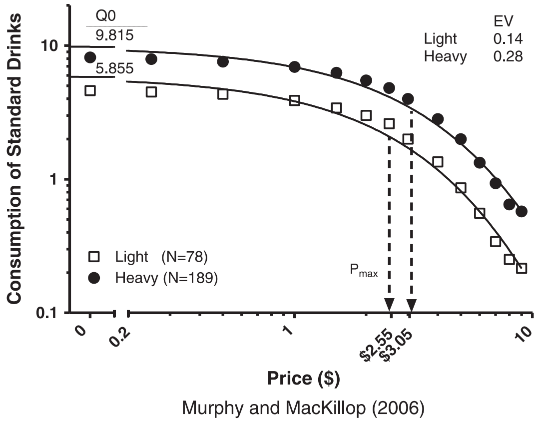

Figure 11. The reported consumption of standard alcoholic drinks as a function of the cost of each drink from two groups of college undergraduates, one group self-reporting light consumption ($n = 78$) and one group reporting heavy consumption ($n = 189$). Subjects responded to a set of questions about hypothetical alcohol consumption (from Murphy and MacKillop, 2006). EV, essential value.

example, consider a policy that would encourage the use of an alternative ethanol-based fuel for automobiles. Even if the price of the fuel was 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. 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 offers a data-driven approach for evaluating the impact of these incentives on expected consumption at the individual, market, and population levels, providing an empirical basis for a rational cost-benefit analysis of the proposed policy.

To illustrate how disincentives and contextual variables may be evaluated with HPTs, Gentile *et al.* (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 AM, 10:00 AM, or 12:30 PM) 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 EVs of alcohol, or greater sensitivity to price increases, compared with the no-constraint control. The results are plotted in Figure 12 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 contextual 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.

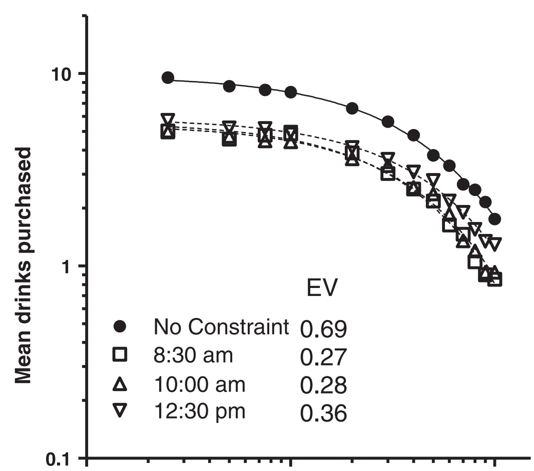

Figure 12. The reported consumption of standard alcoholic drinks as a function of the cost of each drink from college undergraduates ($N = 164$) randomly assigned to one of the three hypothetical academic constraints (academic classes scheduled at 8:30 AM, 10:00 AM, and 12:30 PM) or a control condition: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

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While the results in Figure 12 are encouraging, research is needed to establish that hypothetical estimates of demand are valid predictors of actual consumption behavior. Although most HPT work has been in the domain of substance abuse, results so far are encouraging (Reed *et al*., 2014). For example, studies of hypothetical demand have been shown to correlate significantly with alcohol self-administration (Amlung *et al*., 2012) and self-reported levels of naturalistic smoking and nicotine dependence (MacKillop, *et al*., 2008).

CONCLUSIONS

At its heart, behavioral economics attempts to apply concepts developed by micro-economists 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. Studies of hypothetical demand with large samples of human subjects indicate that this methodology has generality to demand curve analysis of entire consumer populations. 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. EV, 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 (Oliveira-Castro *et al*., 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 corporate decision-making and empirical public policy (Magoon and Hursh, 2011; Hursh and Roma, 2013).

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NOTE

1. 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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