A Cue-Theory of Consumption

A CUE-THEORY OF CONSUMPTION*

DAVID LAIBSON

Psychological experiments demonstrate that repeated pairings of a cue and a consumption good eventually create cue-based complementarities: the presence of the cue raises the marginal utility derived from consumption. In this paper, such dynamic preferences are embedded in a rational choice model. Behavior that arises from this model is characterized by endogenous cue sensitivities, costly cue-management, commitment, and cue-based spikes in impatience. The model is used to understand addictive/habit-forming behaviors and marketing. The model explains why preferences change rapidly from moment to moment, why temptations should sometimes be avoided, and how firms package and position goods.

I. INTRODUCTION AND MOTIVATION

> The patient was a 28-year-old man with a ten-year history of narcotic addiction. He was married and the father of two children. He reported that, while he was addicted, he was arrested and incarcerated for six months. He reported experiencing severe withdrawal during the first four or five days in custody, but later, he began to feel well. He gained weight, felt like a new man, and decided that he was finished with drugs. He thought about his children and looked forward to returning to his former job. On the way home after his release from prison, he began thinking of drugs and feeling nauseated. As the subway approached his stop, he began sweating, tearing from his eyes, and gagging. This was an area where he had frequently experienced narcotic withdrawal symptoms while trying to acquire drugs. As he got off the subway, he vomited onto the tracks. He soon bought drugs and was relieved. The following day he again experienced craving and withdrawal symptoms in his neighborhood, and he again relieved the symptoms by injecting heroin. The cycle repeated itself over the next few days and soon he became readdicted [O'Brien 1976, p. 533].

Environmental cues sometimes elicit changes in preferences/behavior. Hence, cues and consumption are sometimes complements: cues raise the marginal utility of consumption. The narrative above describes an unusually powerful case of this

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phenomenon. Few of us ever experience cue-consumption complementarities as potent as those of the heroin addict. However, less extreme examples are commonplace. Consider cues like the smell of cookies baking, smell of perfume/cologne, sound of ice falling into a whiskey tumbler, sight of a bowl of ice cream, and sight of a pack of cigarettes.

Preferences are sensitive to cues like these, explaining why those preferences often vary from moment to moment. The sight of a dessert tray at the end of a meal will induce a diner to order something sweet, reversing an earlier resolution to forgo the extra calories. Likewise, the sight of a familiar drug-taking environment will induce drug craving in an addict, even if the addict has just completed a six-month detoxification therapy. Cues generate high frequency variation in preferences/cravings, explaining apparently random behavior. Cues also play a role in the marketing strategies of firms (e.g., supermarkets create artificial food smells to stimulate shopper demand and surround checkout aisles with candy). Moreover, when consumers understand these mechanisms, consumers try to influence the sequence of cues they experience (e.g., recovering alcoholics avoid the smell or sight of alcohol). Cues serve as an important endogenous variable, which firms, consumers, and governments try to control.

This paper argues that cues are an important determinant of habit-forming behaviors and that cue effects can be captured using minor variants of the models that Becker and Murphy have developed in their papers on rational addiction and advertising [1988, 1993]. The Becker-Murphy rational addiction model assumes that past consumption is complementary with current consumption, thereby explaining the formation of habits and addictions. The Becker-Murphy advertising model assumes that advertisements (i.e., sensory inputs like cues) are complementary with consumption, formalizing the role of marketing. The current paper draws a connection between these two heretofore distinct forms of complementarity.

The connection is already discussed in the psychology literature. For example, it is known that heroin addicts experience a heightened desire (i.e., marginal utility) for heroin consumption when they experience the cues associated with past use of heroin. Likewise, cigarette smokers experience a heightened nicotine craving when they see smoking cues, like an open box of cigarettes. The cues model in the current paper captures these patterns by assuming that habit formation effects are turned on and off by the presence or absence of cues (i.e., sensory inputs) that have been associated with past consumption of habit-forming goods. Hence, the cues model assumes that a current cue is complementary with current consumption if that cue has been associated with consumption in the past. For example, if the sound of ice cubes falling into a tumbler has reliably predicted ingestion of Scotch in the past, then that sound will elevate the current marginal utility of Scotch (i.e., will increase one's desire for a glass of Scotch). Likewise, if the smell of baking cookies has reliably predicted feeding in the past, then the current smell of baking cookies will elevate the current marginal utility of feeding.

This paper documents and explains the existence of such a dynamic utility function, using psychological evidence. The paper then models the choices of a rational decision maker who has cue-contingent habit formation. The decision-maker can manipulate the dynamic pairing of cues and behavior as well as cue-exposure. The model embeds these preferences in a rational choice framework that is closely related to the habit formation model of Becker and Murphy [1988], and assumes an underlying stable meta-utility structure [Becker 1996].

In the body of the paper I highlight four implications of the cues model. First, the model generates multiple steady states, some of which are characterized by cue-contingent marginal utility effects (i.e., cue-based drives). In these cue-based steady states, equilibrium actions vary at high frequency and depend on seemingly arbitrary cues (i.e., white noise that is uncorrelated with any other exogenous variable in the consumer's problem). Second, the cues model predicts that consumers will engage in active cue-management. Under reasonable parameter specifications, consumers are willing to spend almost all of their income to manipulate the sequence of cues they experience. Hence, arbitrary cues have important welfare implications. Third, the model predicts that consumers will pay to reduce their own future choice set, even though the consumers have dynamically consistent preferences. This paradoxical commitment arises because in some versions of the model, choice sets are linked one-to-one with cues (you cannot smoke a cigarette without seeing one). Hence, large choice sets introduce cue-based temptations that are costly to resist. Fourth, links between cues and rewards imply that the presence of reward opportunities may generate drives that make delay of gratification difficult. This explains why consumers often exhibit extreme impatience over the short run (when the reward opportunity cue is present), while maintaining a long-run preference for patience.

The paper is organized as follows. Section II summarizes relevant psychology research, and then presents a dynamic choice model that integrates these findings. In addition, Section II characterizes the solution of the model. Section III interprets the model and formally establishes the results outlined here. Section IV contrasts the view of habits discussed in this paper with the now standard model of habits presented in Becker and Murphy [1988]. The new model explains why tastes and cravings change rapidly from moment to moment, why temptations should sometimes be actively avoided, how firms position and package goods, and why public consumption generates negative externalities. Section V concludes.

II. Preferences

This section presents a stable meta-utility function [Becker 1996]. Its *functional form* is fixed by nature and is beyond control of the consumer. The following subsection summarizes psychological evidence that motivates this functional form.

II.1. Psychological Evidence on Preference Dynamics

Classical conditioning experiments pair a behaviorally neutral cue—e.g., bells in Pavlov's [1904] dog experiment—with a behaviorally nonneutral stimulus—e.g., a feeding opportunity. In Pavlov's experiment the food elicits salivation. Repeated pairings of the bells and the food eventually lead the bells to generate the same salivatory response that was originally generated by the feeding. Ringing the bells elicits salivation whether or not the bell is followed by a feeding session. Psychologists call cue-elicited behavior "conditioned responses." Many (but not all) conditioned responses are physiologically preparatory; e.g., for Pavlov's dogs, salivation prepares the organism for food ingestion. Such preparatory responses are generally evolutionarily adaptive. The organism's fitness is improved by cue-triggered preparatory mechanisms that are based on past associations between cues (the ringing bells) and behavior (feeding).[1]

Dozens of studies document the existence of such automatic

1. This paper explores the role of preparatory conditioned responses. For a discussion about the scope of preparatory conditioning phenomena, see Solomon

physiological mechanisms.[2] For example, exposure to food cues (e.g., visual, oral, spatial, or temporal) initiates a host of specialized digestive processes: salivary, gastric, pancreatic exocrine, pancreatic endocrine (insulin), thermogenic, and cardiovascular.[3] Analog preparatory mechanisms are initiated when organisms are exposed to familiar drug cues. Many of these preparatory mechanisms are physiologically compensatory in the sense that they compensate for or offset the effect of the drug. For example, rats that have repeatedly received anaesthetizing morphine injections in the presence of a particular cue eventually develop an *increased* responsiveness to pain (hypersensitivity) in the presence of that cue.[4] This cue-conditioned hypersensitivity partially offsets the anaesthetic effect that will be generated if the rat is subsequently injected with morphine. Offsetting the morphine-induced anaesthetic effect is adaptive, since the anaesthetic effect reduces the ability of the organism to respond effectively to external stimuli. When animal (including human) drug users do not have the benefit of using familiar cues to anticipate and offset drug effects, they experience much higher rates of overdose.[5]

Cue-triggered preparatory/compensatory responses tend to raise the marginal utility of consumption. For example, cue-triggered salivation and gastric secretion raise one's appetite for food. Numerous studies demonstrate that the presentation of food cues elevate appetite.[6] Likewise, cue-triggered hypersensitivity raises one's valuation for an anaesthetic drug like morphine.[7] The subjective "craving" of the decision-maker described in the story

[1980], Stewart and Eikelboom [1987], Siegel, Krank, and Hinson [1988], Turkkan [1989], and the commentaries that accompany the Turkkan paper.

2. Other domains include language, memory, social competition, aggression, play, substance abuse, pharmacology, immunology, exercise physiology, stress, digestive physiology, skeletal response systems, cardiovascular functioning, sexual behavior, maternal lactation, and infant suckling. See Siegel, Krank, and Hinson [1988], Turkkan [1989], Hollis [1997], and Domjan, Cusato, and Villareal [2000].

3. See Mattes [1997], Rogers [1989], Simon [1986], Woods et al. [1977], and Woods [1991].

4. See Siegel [1975].

5. Heroin tolerance is relatively low when heroin is injected in an environment that does not contain the set of cues associated with past use, making "overdose" from previously tolerated doses more likely in unusual injection environments [Siegel, Hinson, Krank, and McCully 1982].

6. See Booth, Lee, and McAleavey [1976], Cornell, Rodin, and Weingarten [1989], Federof, Polivy, and Herman [1997], Lambert [1991], and Weingarten [1984].

7. Clinicians commonly report that drug-associated environmental cues elicit withdrawal symptoms and relapse in long-detoxified former addicts [Siegel, Krank, and Hinson 1988].

at the beginning of this paper provides an example of how strong this cue-induced marginal utility effect can be. A less dramatic example involves a smoker . . .

> who had been a nicotine addict but hadn't smoked for years. He had abstained from cigarettes in a variety of situations where he had smoked in the past, and thus he had desensitized himself to a variety of conditioned associations—cigarettes at parties, cigarettes at morning coffee, cigarettes at the desk, and so on. One day he went to the beach and was suddently overwhelmed by an intense craving to smoke. He found this beyond understanding until he realized that smoking on the beach had been an important pattern at one time in his life, and that he had not had the opportunity to eliminate that particular conditioned association [Goldstein 1994, pp 221–222].[8]

Such cue-based motivational effects arise in a wide range of domains, including feeding, drug use, sexual activity, social competition, aggression, and exercise/play.

In summary, repeated pairings of cues and behavior elicits cue-contingent conditioned responses. Such responses are often functionally preparatory or compensatory, and effectively elevate an organism's appetite (i.e., marginal utility) for the consumption event that has historically followed the anticipatory cues.

II.2. Formal Model

The following model illustrates the psychological effects discussed above. It is presented as a model of drug use, but the principles explored below apply to many other types of habitual consumption.

Time is discrete, indexed by the nonnegative integers, $t \in \{0,1,2, \ldots\}$. Each time period a random cue takes on one (and only one) of two values: *RED* or *GREEN*.[9]

$$\Pr[RED] = \mu^R \tag{1}$$

$$\Pr[GREEN] = 1 - \mu^R \equiv \mu^G. \tag{2}$$

8. This quote was brought to my attention by Elster [1999].

9. The analysis assumes that only two cues exist and that they are readily distinguished. Naturally, most cues belong on a continuum. A complete model of cues would need to evaluate consumers' capacities to discriminate among cues ("discrimination gradient") and consumers' propensities to generalize from one cue to other related cues ("generalization gradient"). For example, would a heroin addict who experiences conditioned craving when he sees his dealer also experience conditioned craving when he sees his dealer's girlfriend? For experimental evidence on generalization gradients in nonhuman animals, see Hoffman, Fleshler, and Jensen [1963], Richardson, Williams, and Riccio [1984], and Cheng, Spetch, and Johnston [1997].

Each period the consumer chooses between two activities: an activity that can be repeated over time, and some alternative activity that changes every period and hence is not capable of being influenced by conditioning effects. (Recall that conditioned responses are built up through repetitive associations between cues and a particular consumption activity.) I will refer to the repeatable activity as the primary activity.

Each period the consumer must choose either the primary or alternative activity. This is a zero-one decision, and it is made contingent upon the realization of the cue process. Let $a_t^R \in \{0,1\}$ represent the consumer's action choice contingent on a *RED* cue in time period t. Let $a_t^G \in \{0,1\}$ represent the consumer's action choice contingent on a *GREEN* cue in time period t. A 0 represents a choice to engage in the alternative activity. A 1 represents a choice to engage in the primary activity. For example, if the consumer were to choose $a_t^R = 1$, $a_t^G = 0$, the consumer would engage in the primary activity if the cue turned out to be *RED* that period, and the consumer would engage in the alternative activity if the cue turned out to be *GREEN*.

The consumer's physiology is characterized by two compensatory processes: x_t^R, a compensatory process activated by the *RED* cue; and x_t^G, a compensatory process activated by the *GREEN* cue. When the *RED* cue appears, compensatory process x_t^R is activated, and is strengthened or weakened according to the process:

$$x_{t+1}^R = \alpha x_t^R + (1 - \alpha)a_t^R. \tag{3}$$

When the *RED* cue appears, compensatory process x_t^G is not operational, and does not evolve:[10]

$$x_{t+1}^G = x_t^G. \tag{4}$$

The outcome is flipped when the *GREEN* cue appears. In this case, compensatory process x_t^G is operational, and is strengthened or weakened according to the process:

10. The assumption that the compensatory process does not evolve if the cue is not present is consistent with the available evidence on "extinction" (see Institute of Medicine [1996, pp. 42] and Hoffman, Fleshler, and Jensen [1963]). Recall the example of the ex-smoker who had not extinguished his association between beach cues and smoking. Cue-based drives do not decay on their own. The cue-conditioned addict must be desensitized by repeatedly exposing the individual to the cue while abstaining from consumption of the addictive good. Finally, assuming that the cue-based drive decays in the absence of the cue, would not change most of the qualitative analysis.

(5) $$x^G_{t+1} = \alpha x^G_t + (1 - \alpha)a^G_t.$$

and compensatory process x^R_t is not operational and does not evolve:

(6) $$x^R_{t+1} = x^R_t.$$

These cue-sensitive transition processes imply that x^R_t is a weighted average of the consumer's past actions in periods when the *RED* cue appeared. Likewise, x^G_t is a weighted average of the consumer's past actions when the *GREEN* cue appeared. Finally, note that x^R_0 and x^G_0 are assumed given, and lie inside the unit interval. This implies that all future values of x^R_t and x^G_t also lie in the unit interval.

The consumer's instantaneous utility function is cue-contingent. When the *RED* cue appears, instantaneous utility is given by

(7) $$u(a^R_t - \lambda x^R_t) + (1 - a^R_t)\xi,$$

where ξ is the value (in utils) of the alternative activity, $u(\cdot)$ is increasing and strictly concave, and $0 < \lambda < 1$.

Likewise, when the *GREEN* cue appears, instantaneous utility is given by

(8) $$u(a^G_t - \lambda x^G_t) + (1 - a^G_t)\xi.$$

Four characteristics of these contingent utility functions should be noted.

First, the functional form of this meta-utility function is not chosen by the consumer but is instead biologically predetermined. As numerous authors have argued, conditioned responses are generally evolutionarily adaptive. According to Hollis [1982], "the biological function of classically conditioned responding . . . is to enable the animal to optimize interaction with the forthcoming biologically important event" [p. 3]. I take this dynamic system as a reliable primitive since it is supported by a large body of controlled experiments reported in the neuroscience, pharmacology, and psychology literatures.

Second, the instantaneous utility functions incorporate the compensatory processes in a natural way. The compensatory process offsets the effect of consumption of the primary good. Such offsetting suggests that the compensatory process in this particular model be interpreted as an "opponent process" [Solomon 1980]. Opponent processes are a particular type of compensatory process that partially counteracts the effect of the consumption event.

Third, the preferences in equations (7)–(8) imply that strengthening of the compensatory process is hedonically aversive: $(\partial u[a_t^i - \lambda x_t^i))/\partial x^i < 0$, $i \in \{R,G\}$. This is a standard characteristic of the compensatory processes that are associated with drugs of abuse. These compensatory processes are experienced as craving and withdrawal.[11] However, aversive compensatory processes do not apply to all habitual activities. Consider food cues, like the smell of freshly baked bread. Food cues initiate a compensatory process characterized by appetite arousal and salivation. In general, appetite-arousing compensatory processes elevate the level of utility experienced by the consumer if the consumer actually does eat (i.e., consume the primary good): $\partial u/\partial x^i > 0$, given $a_t^i = 1$. Note that this property does not characterize the preferences in equations (7)–(8). But, this property can be easily modeled. For example, consider preferences given by $u(a_t^i x_t^i - \lambda x_t^i) + (1 - a_t^i)\xi$. Adopting such preferences would not change the results that follow.

Fourth, the ξ term in equations (7)–(8) can be motivated in the following way: assume that the consumer gets perishable income of \$1 every period, which can be allocated to one of two activities—the primary activity (with price \$1 per unit) or the alternative activity (with price \$1) which yields ξ utils per unit.

I assume that the consumer is infinitely lived, and the consumer's instantaneous utility functions are weighted by an exponential discount function with discount factor δ. Then the consumer's value function and Bellman equation are

$$(9) \qquad V(x^R,x^G) = \max_{a^R,a^G} \{\mu^R[u(a^R - \lambda x^R) + (1 - a^R)\xi + \delta V(\alpha x^R + (1 - \alpha)a^R, x^G)] + \mu^G[u(a^G - \lambda x^G) + (1 - a^G)\xi + \delta V(x^R, \alpha x^G + (1 - \alpha)a^G)]\}.$$

Time subscripts have been suppressed, since all variables in the equation above are contemporaneous. This value function represents the welfare of the consumer just before the current period's

11. See Siegel, Krank, and Hinson [1988], pp. 92–93.

appearance of the cue. The first bracketed term is the consumer's welfare conditional on the appearance of the *RED* cue. The second bracketed term is the consumer's welfare conditional on the *GREEN* cue. Finally, note that this Bellman equation representation implies that preferences are dynamically consistent. I will refer to equation (9) as the Cues Bellman equation.

II.3. Parallels to Becker and Murphy [1988]

The Cues Model is related to the addiction model of Becker and Murphy. In the Becker-Murphy model, past consumption of an "addictive" good raises the marginal utility of current consumption of that good.

Compensatory processes, which are embedded in the Cues Model, provide a microfoundation for the complementarity effects which are assumed in the model of Becker and Murphy. Recall that the compensatory variables, x^R and x^G, can be interpreted as "stocks" of past consumption. The equation of motion for x^i ($i \in \{R,G\}$) implies that x^i is a weighted average of the consumer's past actions in periods when the cue of color i has appeared. The instantaneous utility function,

$$u(a^i - \lambda x^i) + (1 - a^i)\xi,$$

implies that a high value of x^i raises the marginal utility associated with consumption of the primary good (i.e., the cross-partial is positive, $\partial^2 u/\partial a^i \partial x^i \geq 0$, since u is concave). Drawing these effects together, past consumption of the primary good raises the value of the stock variable, which in turn raises the marginal utility of current consumption of the primary good. Hence, compensatory processes provide a biological microfoundation for the marginal utility effects in the Becker-Murphy model.

Because of these similarities, the Cues Model embeds the Becker-Murphy Model as a special case. Set $\mu^R = 0$ or $\mu^R = 1$ to retrieve a discrete choice, discrete time version of the Becker-Murphy Model. Note that setting μ^R to either 0 or 1 effectively eliminates the role of the cue. In this case, the Bellman equation can be rewritten as

$$W(x) = \max_a \left[u(a - \lambda x) + (1 - a)\xi + \tilde{\delta} W(\alpha x + (1 - \alpha)a)\right], \tag{10}$$

where we employ a general discount factor $\tilde{\delta}$ in anticipation of results which follow below. To recover a discrete choice, discrete time version of the Becker-Murphy model, set $\tilde{\delta}$ equal to the one-period discount factor, δ.

The model summarized in equation (10) captures the important qualitative properties of the Becker-Murphy Model, but the two models do not nest each other. First, equation (10) assumes a discrete choice, discrete time framework in contrast to the continuous-choice, continuous-time Becker-Murphy framework. More importantly, equation (10) adopts the instantaneous utility function $u(a - \lambda x) + (1 - a)\xi$, where u is any concave function. Becker and Murphy use the utility function, $u(a,x)$, where u is quadratic and concave. Despite these differences, equation (10) captures the critical qualitative properties of the Becker-Murphy model which were discussed at the beginning of this subsection. We refer to equation (10) as the No-Cues Bellman equation.

The model summarized by the No-Cues Bellman equation is closely related to the completely general Cues Model (equation (9)). Hence, it is helpful to begin the analysis in this paper by characterizing the solution of the No-Cues Bellman equation.

PROPOSITION 1. The optimal policy correspondence of the No-Cues Bellman equation is a threshold rule. I.e., there exists threshold value $\hat{x}$ such that

$$a = \begin{cases} 0 & \text{if } x \leq \hat{x} \\ 1 & \text{if } x \geq \hat{x}. \end{cases}$$

All proofs are presented in the Appendix. To develop intuition for this result, recall the instantaneous utility function,

$$u(a - \lambda x) + (1 - a)\xi.$$

A high value of the compensatory process, x, raises the marginal utility associated with consumption of the primary good (i.e., $\partial^2 u/\partial c \partial x \geq 0$). This effect is mitigated, but not completely offset, by dynamic considerations.[12] When the compensatory process is strong, consumption of the primary good is optimal, which is the result in Proposition 1. Hence, the model is said to be character-

12. Specifically, higher current values of the compensatory process raise the future disutility associated with current consumption of the primary good.

ized by "adjacent complementarity": consumption of the primary good increases (weakly) with the stock of past consumption.[13]

The comparative static results for the No-Cues Bellman equation will also prove useful for the analysis of the general model.

PROPOSITION 2. The threshold value $\hat{x}$ is increasing with the discount factor, δ, increasing with the outside option, ξ, and increasing with the compensatory process weighting factor, $1 - \alpha$.

The intuition for these effects is straightforward. First, a higher value of the discount factor, δ, implies that the future takes on greater weight, so current consumption of the primary good generates more future disutility (since future values of x rise with current consumption). Hence, higher δ reduces optimal consumption of the primary good, which implies a higher threshold $\hat{x}$ for primary consumption. Second, a higher value of the outside option, ξ, implies that the alternative good becomes relatively more appealing, generating a higher threshold $\hat{x}$ for primary consumption. Third, a higher value of the weighting factor $1 - \alpha$ implies that current consumption of the primary good has more impact on values of x in the immediate future, and relatively less impact on values of x in the distant future. These effects net out without discounting, but because of discounting the near-term effects dominate. Hence, consumption of the primary good is more costly, which implies a higher threshold, $\hat{x}$, for primary consumption.[14]

II.4. Solution of the Cues Bellman Equation

The Cues Model (equation (9)), is closely related to the No-Cues Model (equation (10)). Specifically, the value function in the Cues Model is a weighted average of modified value functions to the No-Cues Bellman equation.

13. The analysis in Becker and Murphy [1988] focuses on parameter values that imply adjacent complementarity, but their model admits cases in which adjacent complementarity does not arise.

14. Comparative statics with respect to λ cannot be signed unless more structure is imposed on the function u. When u is linear, $\partial\hat{x}/\partial\lambda > 0$, but this inequality reverses when u is sufficiently bowed.

PROPOSITION 3.

$$V(x^R,x^G) = \frac{\mu^R}{1-\delta\mu^G} W\left(x^R \middle| \tilde{\delta} = \frac{\delta\mu^R}{1-\delta\mu^G}\right) + \frac{\mu^G}{1-\delta\mu^R} W\left(x^G \middle| \tilde{\delta} = \frac{\delta\mu^G}{1-\delta\mu^R}\right).$$

Recall that $W(\cdot|\tilde{\delta} = y)$ represents a solution to the No-Cues Bellman equation assuming a discount factor of $\tilde{\delta} = y$. In essence, Proposition 3 implies that the Cues Model is a superimposition of two versions of the No-Cues Model. The first term, $\mu^R/(1 - \delta\mu^G)W(x^R|\tilde{\delta} = \delta\mu^R/(1 - \delta\mu^G))$, represents the discounted value of payoffs that occur when the *RED* cue is present. The second term, $\mu^G/(1 - \delta\mu^R)W(x^G|\tilde{\delta} = \delta\mu^G/(1 - \delta\mu^R))$, represents the discounted value of payoffs that occur when the *GREEN* cue is present. This additive separability arises because the *RED* and *GREEN* compensatory processes temporarily "hibernate" when the other cue appears. For example, when the *GREEN* cue is present, the *RED* process does not influence instantaneous utility and does not evolve.

However, the Cues Model is not an exact superimposition of two No-Cues Models, since the modified discount factors, $\delta\mu^R/(1 - \delta\mu^G)$ and $\delta\mu^G/(1 - \delta\mu^R)$, are both less than δ (the true discount factor). These modified discount factors reflect the property of the Cues Model that current consumption of the primary good only has an impact on future periods in which the cue realization is the same as the current cue realization. This effect mitigates the future cost of current primary good consumption, and is captured by adopting a lower discount factor in the calculation of W. Heuristically, $\delta\mu^R/(1 - \delta\mu^G)$ is just the expected value of the discount factor that will apply between the current period and the next period in which the *RED* cue is present:

$$\mu^R\delta + \mu^G\mu^R(\delta)^2 + (\mu^G)^2\mu^R(\delta)^3 + \ldots = \delta\mu^R/(1 - \delta\mu^G).$$

Likewise, $\delta\mu^G/(1 - \delta\mu^R)$ is just the expected value of the discount factor that will apply between the current period and the next period in which the *GREEN* cue is present.

Finally, the terms that weight the value functions in Proposition 3 adjust the future weightings so that the sum of weights over all future *RED* periods and all future *GREEN* periods are, respectively, equal to $\mu^R/(1 - \delta)$ and $\mu^G/(1 - \delta)$. For example,

$$\frac{\mu^R}{1-\delta\mu^G}\left[1+\left(\frac{\delta\mu^R}{1-\delta\mu^G}\right)+\left(\frac{\delta\mu^R}{1-\delta\mu^G}\right)^2+\ldots\right]=\frac{\mu^R}{1-\delta}.$$

A formal proof of Proposition 3 appears in the Appendix.

Using Proposition 3 and our earlier results on threshold rules and comparative statics in the No-Cues Model (Propositions 1 and 2), we are now in a position to characterize the optimal policy associated with the Cues Model.

COROLLARY 4. The optimal policy correspondence of the Cues Bellman equation is a threshold rule. I.e., there exist threshold values $\hat{x}^R$ and $\hat{x}^G$ such that

$$a^R=\begin{cases}0 & \text{if } x^R \le \hat{x}^R\\ 1 & \text{if } x^R \ge \hat{x}^R\end{cases}$$
$$a^G=\begin{cases}0 & \text{if } x^G \le \hat{x}^G\\ 1 & \text{if } x^G \ge \hat{x}^G.\end{cases}$$

Without loss of generality assume that $\mu^R \le \mu^G$. Then $\hat{x}^R \le \hat{x}^G \le \hat{x}$, where $\hat{x}$ is the threshold value from the optimal policy generated by the No-Cues Bellman equation ($\tilde{\delta} = \delta$).

This threshold rule follows from Propositions 1 and 3: a threshold rule solves the No-Cues Model, and the Cues Model is a superimposition of two modified versions of the No-Cues Model, so the Cues Model also generates a threshold rule.

The inequality, $\hat{x}^R \le \hat{x}^G \le \hat{x}$, follows from Proposition 2. The comparative statics results in Proposition 2 imply that the optimal threshold value falls with the discount factor. When $\mu^R \le \mu^G$, the effective discount factors in Proposition 3 obey the inequalities, $\delta\mu^R/(1-\delta\mu^G) \le \delta\mu^G/(1-\delta\mu^R) \le \delta$, implying that $\hat{x}^R \le \hat{x}^G \le \hat{x}$. Intuitively, relative to the No-Cues Model, the Cues Model implies that today's consumption is less likely to affect tomorrow's utility flow since tomorrow the consumer may experience the other cue. This makes consumption of the primary good more appealing, lowering the threshold values below $\hat{x}$.

Proposition 2 also generalizes to the Cues Model.

COROLLARY 5. The threshold value $\hat{x}^R$ is increasing with the discount factor δ, increasing with the outside option ξ, increasing with the compensatory process weighting factor $1-\alpha$, and increasing with the probability of the *RED* cue, μ^R. The threshold value $\hat{x}^G$ changes with the same signs, except $\hat{x}^G$

FIGURE I
Steady States and Basins of Attraction

increases with the probability of the *GREEN* cue, $\mu^G \equiv 1 - \mu^R$.

These results follow from the fact that the Cues Model is a superimposition of two No-Cues Models, in which the discount factor, δ, is replaced by the effective discount factors, $\delta\mu^R/(1 - \delta\mu^G)$ and $\delta\mu^G/(1 - \delta\mu^R)$. Note that these effective discount factors both increase with δ, while the first discount factor increases with μ^R, and the second discount factor increases with μ^G. Higher (effective) discount factors imply higher thresholds for consumption of the primary good, since the future is effectively weighted more heavily.

III. INTERPRETATION AND ANALYSIS

III.1. Dynamics and Steady States

The model described above has two state variables: x^R and x^G. The evolution of the state variables is characterized by four basins of attraction in $\langle x^R, x^G \rangle$ space (Figure I).

For example, consider an actor with physiological state variables $\langle x_t^R, x_t^G \rangle$ lying in the interior of the North-West basin of attraction in Figure I. This implies that

$$0 < x_t^R < \hat{x}^R$$

$$\hat{x}^G < x_t^G < 1,$$

where $\hat{x}^R$ and $\hat{x}^G$ are the threshold values from Corollary 4. These inequalities imply that the *RED* cue elicits a relatively weak conditioned compensatory response (x_t^R) and the *GREEN* cue elicits a relatively strong conditioned compensatory response (x_t^G). By Proposition 1, $a_t^R = 0$, and $a_t^G = 1$: the consumer chooses the alternative activity when the cue is *RED,* and chooses the primary activity when the cue is *GREEN.*

These cue-contingent actions can be used to derive the one-period evolution of the state variables. If the cue realized in period t is *RED,* then

$$x_{t+1}^R = \alpha x_t^R + (1 - \alpha) a_t^R = \alpha x_t^R < x_t^R$$
$$x_{t+1}^G = x_t^G.$$

If the cue realized in period t is *GREEN,* then

$$x_{t+1}^R = x_t^R$$

$$x_{t+1}^G = \alpha x_t^G + (1 - \alpha) a_t^G = \alpha x_t^G + (1 - \alpha) > x_t^G.$$

Hence, either x_t^R will fall, or x_t^G will rise, and hence $\langle x_{t+1}^R, x_{t+1}^G \rangle$ will lie in the North-West basin of attraction. Given the iid distribution of the cue realization, the two state variables will converge with probability one to a steady state $\langle x^R, x^G \rangle = \langle 0,1 \rangle$.[15] A simulated partial convergence path is drawn in Figure I.

In the preceding analysis, the weak conditioned compensatory response elicited by the *RED* cue is self-reinforcing. The weak compensatory response implies that it is optimal for the consumer to choose the alternative activity in the presence of the *RED* cue. This further weakens the compensatory process associated with the *RED* cue. Likewise, the strong conditioned compensatory response elicited by the *GREEN* cue is self-reinforcing. This strong compensatory response implies that it is optimal for

15. A steady state exists at time period T if the state variables are constant from T forward:

$$\Delta x_t^R = \Delta x_t^W = 0 \quad \forall\, t \geq T.$$

the consumer to choose the primary activity in the presence of the *GREEN* cue. This further strengthens the compensatory process associated with the *GREEN* cue.

The discussion above has focused on one of the four basins of attraction. Analogous arguments apply to the other basins of attraction.

COROLLARY 6. Fix parameters for the Cues Model. Assume that these parameters generate threshold values $\hat{x}^R$ and $\hat{x}^G$ in the interior of the unit interval. Then, there exist four locally stable steady states:

$$\langle x^R, x^G \rangle = \begin{cases} \langle 0,0 \rangle \\ \langle 0,1 \rangle \\ \langle 1,0 \rangle \\ \langle 1,1 \rangle . \end{cases}$$

The existence of these four steady states follows from arguments analogous to those described at the beginning of this subsection. These arguments depend on both Proposition 1 and the equations of motion for the state variables, equations (3)–(6).

The two steady states in the Cues Model that are characterized by no cue-sensitivity ($\langle x^R, x^G \rangle = \langle 0,0 \rangle$ and $\langle x^R, x^G \rangle = \langle 1,1 \rangle$) are analogs of the "no addiction" and "addiction" steady states of Becker and Murphy [1988]. In the $\langle 0,0 \rangle$ steady state of the Cues Model, the optimal action is to never engage in the primary activity, regardless of the cue outcome. In the $\langle 1,1 \rangle$ steady state of the Cues Model, the optimal action is to always engage in the primary activity, regardless of the cue outcome.

III.2. Cue-Sensitivity

The difference between the Cues Model and the Becker-Murphy Model is highlighted by the two steady states in which behavior is cue-sensitive: $\langle x^R, x^G \rangle = \langle 0,1 \rangle$ and $\langle x^R, x^G \rangle = \langle 1,0 \rangle$. In these steady states, the actions of the consumer depend on realizations of the cue process. For example, at the $\langle 0,1 \rangle$ steady state, the consumer engages in the alternative activity when the cue is *RED* and engages in the primary activity when the cue is *GREEN*. Hence, actions depend on the cue process, even though the cue process is arbitrary in the sense that the sequence of cues is independent of all other exogenous variables in the consumer's problem. Conditioned responses explain how "neutral" cues come to generate "real" effects. The intuition behind this result is straightforward. A cue matters because the cue has been associated previously with primary consumption; this association has generated a cue-contingent compensatory process, which creates a cue-contingent marginal utility effect, which leads the consumer to choose actions that reinforce the association between cues and primary consumption.

III.3. Cue-Management

If cues affect welfare, then one would expect that consumers will attempt to influence those cues. One way to calibrate the importance of cue effects is to ask how much a consumer would pay to control the cue process. It is helpful to recall the earlier motivation for the ξ term in the instantaneous utility function: "Assume that the consumer gets perishable income of $1 every period, which can be allocated to one of two activities: the primary activity (with price of $1 per unit) or the alternative activity (with price $1) which yields ξ utils per unit." I want to measure the consumer's willingness to give up this income, in return for the capacity to permanently control the cue process. The next Proposition shows that the willingness to pay can be made arbitrarily close to all of the consumer's income.

PROPOSITION 7. For any $\kappa < 1$, there exist preferences and cue probabilities that support a steady state at which the consumer is willing to give up at least κ proportion of her permanent income to permanently control the cue process. No such parameterization exists if $\kappa \geq 1$.[16]

This proposition is proved in the Appendix. The idea behind Proposition 7 is that a parameterization can be found which drives the consumer's payoff at a particular steady state to $u(0)/(1 - \delta)$. For intuition, consider the case where λ is close to one (making the compensatory process very effective), μ^R is close to one (making the *RED* cue very common), x^R is one (making the *RED* compensatory process strong), and x^G is zero (making the *GREEN* compensatory process weak). Then, subject to two other necessary conditions, the consumer is at a steady state in which a realization of the *RED* cue induces a strong compensatory response that makes consumption of the primary good optimal.

16. For scenarios in which the consumer gives up $\kappa > 1$ proportion of income, I assume zero consumption of the primary good and negative consumption of the alternative good. E.g., if income is $1 - \kappa < 0$, then consumption of the alternative good is $1 - \kappa$ units generating $\xi(1 - \kappa)$ utils.

This consumer would give up almost all of her permanent income to force the cue to be *GREEN* for all future t.

Proposition 7 formalizes the prediction that cues play a potentially important role in welfare analysis.[17] These predictions match up well with reality. Cue-management is a commonly observed behavioral and therapeutic technique. Real-life consumers routinely manipulate the cues that they experience. For example, ex-alcoholics avoid bars, dieters keep snack food out of view, and parents choose the candy-free checkout aisles at supermarkets.[18] One weight management program offers the following analysis:

> Jar of candy on the desk . . . sure I'll have some. Strolling past a bakery . . . the donuts sure smell good. Popcorn at the movies . . . I can't resist. Snacks while watching TV . . . the whole family does it. It's just about impossible to isolate yourself from food and the various signals that remind you of food. In our society, we're bombarded with tempting treats that lure us into unplanned eating episodes. So what can you do? [. . .] You can eliminate some triggers, such as bowls of candy sitting on your desk. You can stop buying foods where "you can't eat just one" [Wellbridge Weight Management Approach 1998, Section 5, p. 8].

In addition, "cue-desensitization" techniques are now being used by therapists with patient populations suffering from phobias and addictions [Jansen 1998; Monti et al. 1993; Wardle 1990]. For example, one recently developed technology

> places the addict seeking treatment in an immersive virtual reality rig. While a headset displays a video from a laser disc, sensors monitor respiration rate, pulse rate, perspiration and skin temperature; therapists correlate spikes in bodily responses to particular scenes from the videodisc. Once the triggers are identified, [the company] exposes its clients to the most provocative scenes over and over again. By watching the instrumentation readouts, the subjects learn to suppress their cravings [Brody 1999, p. 29].

In terms of the Cues Model, cue-desensitization techniques help addicts lower the value of the cue-contingent compensatory processes, x^R and x^G.[19]

17. At the Becker-Murphy steady states the consumer is unwilling to give up any income to control the cue process. At these steady states cues affect neither actions nor welfare.
18. Alternatively, these decisions can be explained with dynamically inconsistent preferences.
19. Analogously, Becker-Murphy consumers who experience aversive addictions would like to be able to lower their accumulated consumption capital.

III.4. A Different Cue Structure

So far, I have assumed that the cue process is independent of the other exogenous variables in the consumer's problem. This assumption leads the model to understate the importance and likelihood of cue-sensitivities. I now discard this assumption. This modeling switch is sensible, since most real-world cues are highly correlated with reward opportunities. For example, it is difficult to smoke a cigarette without first seeing one—i.e., seeing a cigarette cue:

> Contrary to what most people might think, craving is not provoked by the absence of the drug to which a person was addicted, but by its presence—that is, by its availability. This is illustrated by the nicotine addict who goes skiing for a whole day, leaving cigarettes behind. No thought is given to cigarettes—they are simply unavailable. Then back at the lodge, where nicotine is available again, intense craving strikes, and the addict lights up [Goldstein 1994, p. 222].[20]

With the experience of the skier in mind, consider the following slightly altered version of the earlier model. The new model and the old model are identical except that in the new model, the consumer can only engage in the primary activity when the cue is *RED*. This is a physical constraint on the consumer. For example, imagine that a consumer can only smoke a cigarette (i.e., engage in the primary activity) when she experiences the cigarette availability cue (i.e., sees the *RED* cue).

With these assumptions, the consumer's value function becomes

$$(11) \qquad V(x^R,0) = \max_{a^R,a^G} \{\mu^R[u(a^R - \lambda x^R) + (1 - a^R)\xi + \delta V(\alpha x^R + (1 - \alpha)a^R,0)] \ldots + \mu^G[u(0) + \xi + \delta V(x^R,0)]\}.$$

Note that this value function is derived by simply setting x^G, $a^G = 0$ in the old value function; $a^G = 0$ since the *GREEN* cue signals the lack of feasibility of engaging in the primary activity; $x^G = 0$ since x^G is a weighted average of the consumer's past choices of a^G.[21] I refer to this as the Restricted Cues Model.

20. This passage was brought to my attention by Elster [1999].
21. I have also set $x_0^G = 0$. This is equivalent to the assumption that the consumer has lived long enough for the *GREEN* compensatory process to have decayed effectively to zero.

Recall that the value function represents the welfare of the consumer before the current period's realization of this cue. The first bracketed term in equation (11) is the consumer's welfare, conditional on the appearance of the *RED* cue (i.e., conditional on the primary activity being available for consumption). The second bracketed term is the consumer's welfare, conditional on the appearance of the *GREEN* cue (i.e., conditional on the primary activity being unavailable for consumption).

The characterization of the general Cues Model (Proposition 3) can be applied to this special case.

COROLLARY 8.

$$V(x^R,0) = \frac{\mu^R}{1-\delta\mu^G} W\left(x^R \middle| \tilde{\delta} = \frac{\delta\mu^R}{1-\delta\mu^G}\right) + \frac{\mu^G}{1-\delta}(u(0)+\xi).$$

The first term, $\mu^R/(1 - \delta\mu^G)W(x^R|\tilde{\delta} = \delta\mu^R/(1 - \delta\mu^G))$, represents the discounted value of payoffs that occur when the *RED* cue is present. The second term, $\mu^G/(1 - \delta)(u(0) + \xi)$, represents the discounted value of payoffs that occur when the *GREEN* cue is present. During periods in which the *GREEN* cue is present, the instantaneous payoff must be $u(0) + \xi$. Hence, in Proposition 3 the term $W(x^G|\tilde{\delta} = \delta\mu^G/(1 - \delta\mu^R))$ is replaced by

$$\frac{u(0)+\xi}{1-\delta\mu^G/(1-\delta\mu^R)},$$

which yields Corollary 8.

The value function in Corollary 8 is just a positive linear transformation of the value function associated with the No-Cues Model (given $\tilde{\delta} = \delta\mu^R/(1 - \delta\mu^G)$). Hence, the value function in Corollary 8 is associated with a maximization problem in which the instantaneous utility function is a positive linear transformation of the instantaneous utility function in the No-Cues Model. Note that optimal policy correspondences do not change when an instantaneous utility function is translated in this way. Hence, Proposition 1 and Corollary 8 jointly imply that the optimal policy correspondence of the Restricted Cues Model is a threshold rule.

COROLLARY 9. The optimal policy correspondence of the Restricted Cues Bellman equation is a threshold rule. I.e., there exists a threshold value $\hat{x}^R$ such that

$$a^R = \begin{cases} 0 & \text{if } x^R \leq \hat{x}^R \\ 1 & \text{if } x^R \geq \hat{x}^R. \end{cases}$$

In addition, $\hat{x}^R \leq \hat{x}$, where $\hat{x}$ is the threshold value from the optimal policy generated by the No-Cues Bellman equation with $\tilde{\delta} = \delta$.

III.5. Commitment as Cue-Management

Subsection III.3 showed that consumers are willing to give up resources to eliminate certain cues. In the Restricted Cues Model (introduced in the previous subsection), such cue-elimination is equivalent to a voluntary reduction in the consumer's choice set. In the Restricted Cues Model cues are inextricably linked to choice sets. (If "smoke a cigarette" is in my choice set, then I possess a cigarette or am able to acquire one, either of which is a smoking cue.)

I adopt the term "pseudo-commitment" to describe a person's decision to reduce her own choice set for the purposes of cue-management. Contrast pseudo-commitment with "classical" commitment, which is driven by dynamically inconsistent preferences. Pseudo-commitment is like classical commitment, because pseudo-commitment implies that consumers will take potentially costly actions which reduce their future choice sets (like intentionally not bringing cigarettes on an outing). But pseudo-commitment differs from classical commitment, because the motive for pseudo-commitment is cue-management. Note that consumers modeled in the current paper have dynamically *consistent* preferences. Pseudo-commitment is driven by the property that cue exposure is hedonically aversive.

In the Restricted Cues Model, the consumer is willing to give up potentially all of her income to achieve cue-management. Since cues and choice sets are linked, this willingness implies that the consumer will potentially engage in highly costly pseudo-commitment.

COROLLARY 10. For any $\kappa < 1$, there exist preferences and cue probabilities of the Restricted Cues Model that support a steady state at which the consumer is willing to give up at least κ proportion of her permanent income to permanently deny herself access to the primary activity. No such parameterization exists if $\kappa \geq 1$.

The intuition behind the corollary parallels that of Proposition 7.

III.6. Impulsivity as Cue-based Drive

Cue-based models predict that actors will exhibit high levels of short-run impatience when exposed to reward-availability cues.[22] Intuitively, cues initiate physiological changes that prime organisms for immediate consumption. When this has occurred, delaying consumption is costly. The consumer must be generously compensated to induce her to willingly resist immediate gratification of a cue-based drive. The following analysis formalizes this intuition.

Recall the Restricted Cues Model, and consider a consumer who is in steady state $\langle x^R, x^G \rangle = \langle 1, 0 \rangle$. Consider the following procedure, which experimentally evaluates the consumer's patience. At time 0, show the consumer the primary consumption good, which, for discussion, is assumed to be a cigarette. Tell the consumer she can either smoke one cigarette at period τ or $1 + \Delta_\tau$ cigarettes at $\tau + 1$. This procedure exposes the consumer to the cigarette cue at period 0 and in the period chosen for consumption.[23] Finally, assume that no other consumption occurs during the course of this experiment. In summary, the subject is offered the following two consumption streams:

	...	$t = \tau$	$t = \tau + 1$	...
Stream A:	0	1	0	0
Stream B:	0	0	$1+\Delta_\tau$	0.

Assume that the subject picks Δ_τ to induce indifference between Streams A and B. To simplify analysis, assume that the periods are sufficiently short so that it is appropriate to set $\alpha = \delta = 1$.

If $\tau = 0$, then Δ_0 is the solution to the equation,

$$(12) \quad u(1 - \lambda x^R) + u(0) = u(-\lambda x^R) + u(1 + \Delta_0 - \lambda x^R),$$

where $x^R = 1$, (recall the steady state assumption). The left-hand side of equation (12) represents the instantaneous payoff of Stream A during periods $t = \tau = 0$ and $t = \tau + 1 = 1$. The cue-induced compensatory process appears in the first term but not the second term on the left-hand side. The cigarette cue is

22. The ideas in this subsection developed from a conversation with Jeroen Swinkels.

23. Alternatively, one could assume that the cigarette will be present until the decision-maker smokes it. This would not change the qualitative results. An earlier version of the paper analyzes this case.

present in period 0 for two reasons: the choice question is posed in period 0, and the good is consumed in period 0.

The right-hand side of equation (12) represents the payoff of Stream B during periods $t = 0$ and $t = 1$. The compensatory process appears in both terms on the right-hand side since the cue is present in period $t = 0$, the period in which the choice question is posed, and in period $t = 1$, the period in which consumption takes place.

If $u(\cdot)$ is linear, then $\Delta_0 = \lambda$. The extra $\Delta_0 = \lambda$ cigarettes compensate the respondent for failing to satisfy the cue-based craving in period 0. This craving is strengthened when $u(\cdot)$ is strictly concave, and in this case $\Delta_0 > \lambda$.

If $\tau \geq 1$, then Δ_τ is the solution to the equation,

$$u(1 - \lambda x^R) + u(0) = u(0) + u(1 + \Delta_\tau - \lambda x^R). \tag{13}$$

The left-hand side of equation (13) represents the payoff of Stream A during periods $t = \tau$ and $t = \tau + 1$ (given $\tau \geq 1$). The compensatory process appears in the first term on the left-hand side, but not in the second term. The cue is present in period τ since Stream A implies that the good is consumed in period τ. Similarly, the right-hand side represents the payoff of Stream B. The compensatory process appears in the second term on the right-hand side since Stream B implies that the good is consumed in period $\tau + 1$.

Regardless of the curvature of $u(\cdot)$, equation (13) implies that $\Delta_{\tau|\tau \geq 1} = 0$. Intuitively, the respondent does not need to be compensated for the delay between periods τ and $\tau + 1$ since consumption in period τ is just as rewarding as consumption in period $\tau + 1$, as long as $\tau \geq 1$. Only period $\tau = 0$ is special, since the respondent experiences a cue-induced craving in period 0 whether or not consumption of the primary good takes place. Posing the cigarette choice question in period 0 exposes the subject to a cigarette cue and elevates the marginal utility of consumption.

Now consider an almost identical experiment, which differs only because the alternative good is now used. The subject chooses between one unit of the alternative good in period τ, or $1 + \Delta'$ units at $\tau + 1$. Again, Δ' is chosen to yield indifference between the two streams. For all $\tau \geq 0$, Δ' solves the equation: $\xi = (1 + \Delta')\xi$. The left-hand side of this equation represents the payoff of Stream A during period $t = \tau$ and the right-hand side of the equation represents the payoff of Stream B during period $t = \tau + 1$. Hence, $\Delta' = 0$.

How would a naive experimenter use these data to impute discount factors? A standard approach would use magnitudes like Δ_0, $\Delta_{\tau|\tau\geq 1}$, and Δ' as estimates for discount rates. What would this imply? Recall that $-\ln(\delta)$ is the actual discount factor of the consumer in this problem. Combining results yields

$$\Delta_0 > \lambda > \Delta_{\tau|\tau\geq 1} = \Delta' = 0 = -\ln(\delta).$$

Hence, the Cues Model predicts that the experimenter will infer falling discount rates if the experiment is conducted with a "primary" good, and a constant zero discount rate if the experiment is conducted with an "alternative" good. The intuition for the former result rests with the cravings that result from the activation of the compensatory process. When a subject first sees a consumption cue for a primary good, she experiences a compensatory process and prefers to consume the good contemporaneously with the compensatory process (i.e., in period 0). If she cannot consume the good in period 0, then she has relatively little preference for one future period versus any other. In summary, the Cues Model draws a distinction between period 0—when the cue-induced craving has been activated by the choice exercise—and all future periods—when the cue-induced craving will be present only if consumption actually occurs. Seeing, and thinking about the primary good in period 0, creates a craving for immediate consumption in period 0.

These predictions match experiments summarized in Mischel, Shoda, and Rodriguez [1992]. The experiments identify cognitive manipulations that enable children to delay gratification. The experimenters gave their subjects the opportunity to either consume a small reward immediately (say, one marshmallow) or wait for a larger reward (say three cookies). During the experiment, both rewards were within reach of the subject. At the beginning of the session, the experimenter told the subject that the experimenter would temporarily leave the room, and that the subject would be allowed to consume the larger reward when the experimenter returned. The subject was also told that she could ring a bell, thereby ending the experiment and enabling the subject to immediately consume the smaller reward, forgoing the larger one. Waiting time was used as a measure of patience.

In one condition, both rewards were covered when the experimenter left the room. With covered rewards, preschool children waited an average of eleven minutes. By contrast, uncovering either or both of the rewards reduced average waiting time to under six minutes. Hence, Mischel et al. find that reward exposure reduces willingness to wait for a delayed reward, even when the reward being exposed is the *delayed* reward.

Laboratory and field studies of time preference find that discount rates are much greater in the short run than in the long run. Hyperbolic discount functions capture this property (e.g., see Ainslie [1992]). The analysis of this subsection, and the experiments reported in Mischel, Shoda, and Rodriguez [1992] suggest that at least some of the hyperbolic discounting effects reflect cue-based drives for immediate consumption.

IV. A New View of Habituated Consumption

The predictions of the Cues Model contrast with the predictions of Becker and Murphy's [1988] habit formation model in three ways.

First, the Cues Model provides a new framework for understanding high frequency variation in craving/marginal utility. Becker and Murphy [1988] argue that consumption binges are driven by variation in different kinds of consumption capital. Becker and Murphy call these "weight" and "eating" capital, and assume that the former is a substitute and the latter a complement to eating:

> Assume that a person with low weight and eating capital became addicted to eating. As eating rose over time, eating capital would rise more rapidly than weight because it [is assumed to have] the higher depreciation rate. Ultimately, eating would level off and begin to fall because weight continues to increase. Lower food consumption then depreciates the stock of eating capital relative to weight, and the reduced level of eating capital keeps eating down even after weight begins to fall. Eating picks up again only when weight reaches a sufficiently low level. The increase in eating then raises eating capital, and the cycle begins again [Becker and Murphy 1988, p. 694].

The Becker-Murphy model predicts that consumption binges are cyclical. However, the available clinical evidence suggests that craving episodes and the binges they induce repeatedly arise with little or no warning and even occur for addicts who have been detoxified for months. Recall the heroin user who experienced a craving in his old neighborhood and the smoker who experienced a craving on the beach. Cravings often arise unpredictably and are "elicited by cues that were associated with drug availability and drug use in the ex-addict's previous experience" [Goldstein 1994, pp. 220–221]. In addition, if an addict experiences a small taste, or "priming" dose of the addictive substance, he will experience extremely strong cravings [Gardner and Lowinson 1993]. Such tastes are themselves an important consumption cue.[24] The Cues Model predicts that seemingly trivial variation in situational cues can elicit temporary but powerful changes in marginal utility. These effects arise in the consumption of a wide range of goods. "Impulse buying" and unplanned consumption are subjects of active study by retail firms and marketing experts. For example, surveys find that between 20 percent and 50 percent of supermarket purchases are unplanned, and that most of these unplanned sales are catalyzed by in-store stimuli.[25] The Cues Model explains much of this behavior, predicting which familiar stimuli—e.g., drug cues, food cues, sexual stimuli,[26] social stimuli[27]—will cause preferences to vary from moment to moment.[28]

Second, the Cues Model explains why and how consumers work to overcome/regulate their habituated appetites. In the Becker and Murphy model, staying in the addicted state is an optimal policy. Addicted consumers would like, in principle, to have less consumption capital, but there is no way for them to optimally achieve this. In the Cues Model, addictive/habitual consumption will be resisted by addicts who can control their environmental cues. The Cues Model predicts many of the specific cue-management and quasi-commitment strategies that habitual consumers commonly use to regulate their own appetites (e.g., hide cigarettes, avoid parties where alcohol will be served, use the candy-free checkout lane, "store tempting treats in 'see proof' containers,"[29] etc.). The model also predicts the successful strategies that people use to delay gratification (e.g., distract oneself

24. See also Institute of Medicine [1996, p. 46].

25. See Abratt and Goodey [1990].

26. See Domjan, Cusato, and Villareal [1999] and Loewenstein, Nagin, and Paternoster [1997].

27. See Domjan, Cusato, and Villareal [1999].

28. See McSweeny and Bierley [1984] for additional work on the relationship between conditioned responses and consumer behavior. In addition, several authors have argued that exposure to credit card insignia elicits conditioned responses. Some existing experiments support this implication. See Feinberg [1986] and McCall and Belmont [1996]. In addition, Prelec and Simester [1998] find that allowing subjects to pay with credit cards raises mean auction bids for goods of uncertain value by approximately 75 percent.

29. E.g., see Wellbridge Weight Management Approach [1998].

during the waiting period).[30] Moreover, the Cues Model predicts many of the strategies that firms use to encourage consumers to make purchases (e.g., install hotel minibars in which snacks and alcohol are visible even if the minibar has not been opened, generate artificial appetite-arousing food smells in supermarkets, package snack food in see-through containers, visually display dessert options in restaurants, "place candy and gum in all [checkout] lanes to take advantage of impulse buying,"[31] etc.). The Cues Model explains how firms create temptation and how/why consumers sometimes avoid it.

Third, the Cues Model explains many of the public dimensions of habitual consumption. The Cues Model implies that cues can be a negative externality. When an individual experiences a food cue (e.g., smell of freshly baked cookies), he will feel an urge to eat. If he is unable to eat, the exposure to the cue will have been aversive. Think how aversive it would be to watch someone else eat a meal if you were not able to join in. The Cues Model implies that food consumption is a jointly complementary activity. Eating should be done as a group. Hence, norms develop to discourage individuals from eating in a public space if others are not also able to eat (e.g., on an airplane, or in a meeting, or at a meal if one's companion's food has not arrived). Firms respond to these norms by carefully timing the presentation of cues (e.g., good waiters try to bring all the entrees to the table simultaneously). If one does need to eat in front of somebody else, the common norm is to offer to share one's food, or to wait until the other person's food arrives. These externalities are particularly strong in the case of drug use. The Cues Model predicts that some addicts and all ex-addicts will be strong supporters of laws that restrict public smoking and public drinking: "With nicotine, someone else's smoking is a potent conditioned cue for lighting up; and that is why regulations that establish smoke-free environments are so helpful to nicotine addicts and ex-addicts in reducing their consumption or maintaining their abstinence" [Goldstein 1994, p. 222]. The negative externalities of public cues may also extend to cues that appear in advertisements. In the United States, advertising for gambling, cigarettes, and alcohol is heavily regulated,

30. See Mischel, Shoda, and Rodriguez [1992] and Jansen [1998].
31. See Wellman [1999].

and has at times been completely banned.[32] Such restrictions are not predicted by the Becker-Murphy model.

The Cues Model bears much in common with Loewenstein's [1996] analysis of visceral factors, "which include drive states such as hunger, thirst and sexual desire, moods and emotions, physical pain, and craving for a drug one is addicted to. The defining characteristics of visceral factors are, first, a direct hedonic impact (which is usually negative), and second, an effect on the relative desirability of different goods and actions" [p. 272]. In the Cues Model, some cues may endogenously become associated with consumption of an addictive good, and when this happens exposure to the cue can be aversive (holding actual consumption constant).[33] Moreover, exposure to the cue will temporarily elevate desire for and consumption of the addictive good. In this sense, the Cues Model is a special case of Loewenstein's more general framework. Both the Cues Model and Loewenstein's analysis describe a world in which behavior changes rapidly from moment to moment, temptations can/should be actively avoided, and public consumption can be a negative externality.

The Cues Model also has much in common with Romer's [2000] model of the physiological microfoundations of preferences. Both the Cues Model and Romer's model use conditioned learning as a microfoundation for preference formation. Although it was developed independently, the Cues Model provides an example of a particular formalization of both Loewenstein's and Romer's analysis.

V. Conclusion

Conditioned responses explain why cues influence motivational states and behavior. Models that incorporate conditioned responses explain a wide range of ostensibly puzzling behavior, including endogenous cue sensitivities, costly cue-management, commitment, and high levels of measured short-term impatience. The Cues Model provides a new framework for understanding addictions. In the Cues Model behavior changes rapidly from

32. For example, since 1934, Federal law and FCC regulations have prohibited broadcasts of gambling advertising. Recently these restrictions have been legally challenged with mixed success. See United States District Court, D. New Jersey [1997] and United States Court of Appeals, Fifth Circuit [1998].

33. The aversiveness of cue-exposure depends on the form of preferences. If preferences take the form $u(a_t^i x_t^i - \lambda x_t^i) + (1 - a_t^i)\xi$, then activation of a cue-conditioned compensatory process may be desirable.

moment to moment, temptations should sometimes be actively avoided, and public consumption can generate a negative externality. This paper illustrates the broader phenomenon that physiology influences preferences. Conditioned cues provide one important physiological lever. Understanding the relationship between physiological mechanisms and preferences will advance models of behavior.

Appendix: Proofs

Proof of Proposition 1. The proof is divided into four lemmas.

Lemma 11. Let

$$f(x) \equiv \sum_{t=0}^{\infty} \delta^t[u(-\lambda\alpha^t x) + \xi]$$

$$g(x) \equiv \sum_{t=0}^{\infty} \delta^t[u(1 - \lambda[\alpha^t x + 1 - \alpha^t])].$$

Then, if these functions cross, there exists a unique intersection point, and $f(\cdot)$ crosses $g(\cdot)$ from above.

Note that $f(\cdot)$ is the payoff function from consuming the alternative good in all current and future periods, and $g(\cdot)$ is the payoff function from consuming the primary good in all current and future periods.

Proof of Lemma 11. By concavity of u,

$$\begin{aligned} f'(x) &= \sum_{t=0}^{\infty} \delta^t(-\lambda\alpha^t)u'(-\lambda\alpha^t x) \\ &< \sum_{t=0}^{\infty} \delta^t(-\lambda\alpha^t)u'(1 - \lambda[\alpha^t x + 1 - \alpha^t]) \\ &= g'(x). \quad \blacksquare \end{aligned}$$

Lemma 12. Let

$$\hat{f}(x) \equiv u(1 - \lambda x) + \sum_{t=1}^{\infty} \delta^t[u(-\lambda[\alpha^t x + \alpha^{t-1}(1 - \alpha)]) + \xi]$$

$$\hat{g}(x) \equiv u(-\lambda x) + \xi + \sum_{t=1}^{\infty} \delta^t[u(1 - \lambda[\alpha^t x + 1 - \alpha^{t-1}])].$$

Then,

$$\hat{f}(x) \geq f(x) \Rightarrow g(x) \geq \hat{f}(x)$$
$$\hat{g}(x) \geq g(x) \Rightarrow f(x) \geq \hat{g}(x).$$

Note that $\hat{f}(\cdot)$ is the payoff function from consuming the primary good in the current period and the alternative good in all future periods. Similarly, $\hat{g}(\cdot)$ is the payoff function from consuming the alternative good in the current period and the primary good in all future periods.

Proof of Lemma 12. We will show that $\hat{f}(x) \geq f(x) \Rightarrow g(x) \geq \hat{f}(x)$, and omit the parallel argument that shows that $\hat{g}(x) \geq g(x) \Rightarrow f(x) \geq \hat{g}(x)$. Let

$$\begin{aligned}
\phi_0(x) &\equiv u(1 - \lambda x) - u(-\lambda x) - \xi \\
\phi_i(x) &\equiv u(-\lambda[\alpha^i x + \alpha^{i-1}(1 - \alpha)]) - u(-\lambda\alpha^i x) \quad (i \geq 1) \\
\psi_i(x) &\equiv u(1 - \lambda[\alpha^i x + 1 - \alpha^i]) \\
&\qquad - u(-\lambda[\alpha^i x + \alpha^{i-1}(1 - \alpha)]) - \xi \quad (i \geq 1),
\end{aligned}$$

where x represents x_t. Note that ϕ_i represents the difference between the $(t + i)$th period instantaneous utility flow generated by $\hat{f}(x)$ and the $(t + i)$th period instantaneous utility flow generated by $f(x)$. Likewise, ψ_i represents the difference between the $(t + i)$th period instantaneous utility flow generated by $g(x)$ and the $(t + i)$th period instantaneous utility flow generated by $\hat{f}(x)$. Note that

$$\begin{aligned}
g(x) - \hat{f}(x) &= \sum_{i=1}^{\infty} \delta^i \psi_i(x) \\
&= \sum_{i=1}^{\infty} \delta^i \left(\psi_i(x) - \sum_{j=0}^{i-1} \phi_j(x) + \sum_{k=0}^{\infty} \delta^k \phi_k(x) \right)
\end{aligned}$$

since $\sum_{i=1}^{\infty} \delta^i(-\sum_{j=0}^{i-1} \phi_j(x) + \sum_{k=0}^{\infty} \delta^k \phi_k(x)) = 0$. Assume that $\hat{f}(x) \geq f(x)$. Then, $\sum_{k=0}^{\infty} \delta^k \phi_k(x) \geq 0$. Hence, to show that $g(x) \geq \hat{f}(x)$, it is sufficient to show that $\psi_i(x) - \sum_{j=0}^{i-1} \phi_j(x) \geq 0$ for all $i \geq$

1. This last inequality follows from concavity of u and the fact that $\alpha x + (1 - \alpha) \geq x$ for all x in the unit interval. ■

LEMMA 13.

$$f(x) \geq g(x) \Rightarrow f(x) \geq \hat{f}(x)$$
$$g(x) \geq f(x) \Rightarrow g(x) \geq \hat{g}(x).$$

Proof of Lemma 13. Suppose that $f(x) \geq g(x)$ and $f(x) < \hat{f}(x)$. Then $\hat{f}(x) > g(x)$, which implies that $f(x) > \hat{f}(x)$, by Lemma 12. This contradiction proves the required result. A similar argument proves the second half of this lemma. ■

LEMMA 14. The solution to the No-Cues Bellman equation

$$W(x) = \max_a [u(a - \lambda x) + (1 - a)\xi + \delta W(\alpha x + (1 - \alpha)a)] \tag{14}$$

is given by

$$W(x) = \begin{cases} f(x) & \text{if } x \leq \hat{x} \\ g(x) & \text{if } x \geq \hat{x}, \end{cases}$$

where $\hat{x}$ is the unique crossing point of $f(\cdot)$ and $g(\cdot)$. If $f(x) > g(x)$ for all x, then $\hat{x} = \infty$. If $f(x) < g(x)$ for all x, then $\hat{x} = -\infty$.

Proof of Lemma 14. Confirm that the Bellman equation is satisfied for the candidate function $W(\cdot)$. Specifically, divide the state space into four regions. First, consider the region characterized by the inequalities: $x < \hat{x}$ and $\alpha x + (1 - \alpha) < \hat{x}$. In this region $f(x) \geq g(x)$ by Lemma 11, and

$$\begin{aligned} W(x) &= f(x) && \text{by assumption} \\ &= \max(f(x), \hat{f}(x)) && \text{by Lemma 13} \\ &= \max_a [u(a - \lambda x) + (1 - a)\xi + \delta f(\alpha x + (1 - \alpha)a)] && \text{by definition of } f \text{ and } \hat{f} \\ &= \max_a [u(a - \lambda x) + (1 - a)\xi + \delta W(\alpha x + (1 - \alpha)a)] && \text{by definition of } W. \end{aligned}$$

Now, consider the region characterized by the inequalities: $x \leq \hat{x}$ and $\alpha x + (1 - \alpha) \geq \hat{x}$. In this region $f(x) \geq g(x)$, by Lemma 11, and

$$
\begin{aligned}
W(x) &= f(x) && \text{by assumption} \\
&= \max\,(f(x), g(x)) && \text{by Lemma 13} \\
&= \max_a\,[u(a - \lambda x) + (1 - a)(\xi + \delta f(\alpha x)) + a\delta g(\alpha x + 1 - \alpha)] \\
& && \text{by definition of } f \text{ and } g \\
&= \max_a\,[u(a - \lambda x) + (1 - a)\xi + \delta W(\alpha x + (1 - \alpha)a)] \\
& && \text{by definition of } W.
\end{aligned}
$$

Parallel arguments apply for the cases in which $x > \hat{x}$, confirming that the Bellman equation is satisfied for the candidate function $W(\cdot)$. ■

Lemma 14 implies that the optimal policy generates payoff function $f(x)$ when $x \leq \hat{x}$, and the optimal policy generates payoff function $g(x)$ when $x \geq \hat{x}$. Payoff $f(x)$ implies permanent abstinence from the primary good. Payoff $g(x)$ implies permanent consumption of the primary good. Hence, the optimal policy is a threshold rule, completing the proof of Proposition 1. ■

Proof of Proposition 2. By Lemma 14, the threshold value $\hat{x}$ is the unique crossing point of the functions $f(x)$ and $g(x)$, defined in the statement of Lemma 11. Let θ represent a parameter of interest in the model. Then by the implicit function theorem,

$$\frac{d\hat{x}}{d\theta} = \frac{f_\theta(\hat{x},\theta) - g_\theta(\hat{x},\theta)}{g_x(\hat{x},\theta) - f_x(\hat{x},\ \theta)}.$$

Note that $g_x(\hat{x},\theta) - f_x(\hat{x},\theta) > 0$, by Lemma 11. So $d\hat{x}/d\theta$ takes the same sign as $f_\theta(\hat{x},\theta) - g_\theta(\hat{x},\theta)$.

To calculate the comparative static on the discount factor, δ, note that

$$f_\delta(\hat{x},\ \delta) = \left(\sum_{i=1}^{\infty} i\delta^{i-1}u(-\lambda\alpha^i\hat{x})\right) + \frac{\xi}{(1-\delta)^2} = \sum_{i=0}^{\infty} \delta^i f(\alpha^{i+1}\hat{x})$$

$$
\begin{aligned}
g_\delta(\hat{x},\ \delta) &= \sum_{i=1}^{\infty} i\delta^{i-1}u(1 - \lambda[\alpha^i\hat{x} + 1 - \alpha^i]) \\
&= \sum_{i=0}^{\infty} \delta^i g(\alpha^{i+1}\hat{x} + 1 - \alpha^{i+1}).
\end{aligned}
$$

Note that $f(\alpha^{i+1}\hat{x}) > g(\alpha^{i+1}\hat{x} + 1 - \alpha^{i+1})\ \forall i$, since f and g are decreasing functions, $\alpha^{i+1}\hat{x} < \hat{x} < \alpha^{i+1}\hat{x} + 1 - \alpha^{i+1}$ $\forall i$, and $f(\hat{x}) = g(\hat{x})$. So $f_\delta(\hat{x},\delta) - g_\delta(\hat{x},\delta) > 0$.

The comparative static on ξ is trivial, since $f_\xi(\hat{x},\xi) - g_\xi(\hat{x},\xi) = 1/(1-\delta) - 0 > 0$.

To calculate the comparative static on α, note that

$$f_\alpha(\hat{x},\alpha) = \sum_{i=1}^{\infty} \delta^i(-\lambda i \alpha^{i-1})(x)u'(-\lambda\alpha^i\hat{x})$$

$$g_\alpha(\hat{x},\alpha) = \sum_{i=1}^{\infty} \delta^i(-\lambda i \alpha^{i-1})(x-1)u'(1-\lambda[\alpha^i\hat{x} + 1 - \alpha^i]).$$

So the difference, $f_\alpha(\hat{x},\alpha) - g_\alpha(\hat{x},\alpha)$, can be broken down into two components:

$$\sum_{i=1}^{\infty} \delta^i(-\lambda i \alpha^{i-1}x)[u'(-\lambda\alpha^i\hat{x}) - u'(1-\lambda[\alpha^i\hat{x} + 1 - \alpha^i])]$$

$$+ \sum_{i=1}^{\infty} \delta^i(-\lambda i \alpha^{i-1})u'(1-\lambda[\alpha^i\hat{x} + 1 - \alpha^i]).$$

Since u is concave and increasing, both series are negative. ■

Proof of Proposition 3. This Proposition is proved with a single Lemma.

LEMMA 15. If $\tilde{W}(\cdot)$ is the solution to the Bellman equation,

$$\tilde{W}(x) = \max_a \mu[u(a - \lambda x) + (1-a)\xi + \delta\tilde{W}(\alpha x + (1-\alpha)a)] + (1-\mu)\delta\tilde{W}(x),$$

then

$$\tilde{W}(\cdot) = \frac{\mu}{1-\delta(1-\mu)} W\left(\cdot \,\middle|\, \tilde{\delta} = \frac{\delta\mu}{1-\delta(1-\mu)}\right).$$

Proof of Lemma 15. Confirm that the Bellman equation is satisfied for the candidate function $\tilde{W}(\cdot)$:

$$\tilde{W}(x) = \frac{\mu}{1-\delta(1-\mu)} W\left(\cdot \,\middle|\, \tilde{\delta} = \frac{\delta\mu}{1-\delta(1-\mu)}\right)$$

$$= \max_a \frac{\mu}{1 - \delta(1-\mu)}$$
$$\times \left[u(a - \lambda x) + (1-a)\xi + \frac{\delta\mu}{1 - \delta(1-\mu)} \right.$$
$$\left. \times\ W\!\left(\alpha x + (1-\alpha)a \,\middle|\, \tilde{\delta} = \frac{\delta\mu}{1-\delta(1-\mu)}\right)\right]$$
$$= \max_a \frac{\mu}{1-\delta(1-\mu)} [u(a - \lambda x) + (1-a)\xi$$
$$+ \delta\tilde{W}(\alpha x + (1-\alpha)a)]$$
$$= \max_a \mu[u(a - \lambda x) + (1-a)\xi$$
$$+ \delta\tilde{W}(\alpha x + (1-\alpha)a)] + (1-\mu)\delta\tilde{W}(x).$$

The first equality follows from the definition of the candidate function. The second equality follows from the definition of W. The third equality follows from the definition of $\tilde{W}$. The fourth equality is derived by rearranging the equation. ■

Continuing with the proof of Proposition 3, let

$$V(x^R, x^G) \equiv \frac{\mu^R}{1 - \delta\mu^G} W\!\left(x^R \,\middle|\, \tilde{\delta} = \frac{\delta\mu^R}{1 - \delta\mu^G}\right) + \frac{\mu^G}{1 - \delta\mu^R} W\!\left(x^G \,\middle|\, \tilde{\delta} = \frac{\delta\mu^G}{1 - \delta\mu^R}\right)$$

and confirm that the candidate function satisfies the Cues Bellman equation:

$$V(x^R, x^G) = \frac{\mu^R}{1 - \delta\mu^G} W\!\left(x^R \,\middle|\, \tilde{\delta} = \frac{\delta\mu^R}{1 - \delta\mu^G}\right)$$
$$+ \frac{\mu^G}{1 - \delta\mu^R} W\!\left(x^G \,\middle|\, \tilde{\delta} = \frac{\delta\mu^G}{1 - \delta\mu^R}\right)$$
$$= \tilde{W}(x^R | \mu = \mu^R) + \tilde{W}(x^G | \mu = \mu^G)$$
$$= \max_{a^R} \mu^R[u(a^R - \lambda x^R) + (1 - a^R)\xi$$

$$
\begin{aligned}
&+ \delta\tilde{W}(\alpha x^R + (1-\alpha)a^R|\mu^R) \\
&+ \delta\tilde{W}(x^G|\mu^G)] \ldots + \max_{a^G} \mu^G[u(a^G - \lambda x^G) \\
&+ (1-a^G)\xi + \delta\tilde{W}(x^R|\mu^R) + \delta\tilde{W}(\alpha x^G + (1 \\
&- \alpha)a^G|\mu^G)] \\
= &\max_{a^R} \mu^R[u(a^R - \lambda x^R) + (1-a^R)\xi \\
&+ \delta V(\alpha x^R + (1-\alpha)a^R, x^G)] \ldots \\
&+ \max_{a^G} \mu^G[u(a^G - \lambda x^G) + (1-a^G)\xi \\
&+ \delta V(x^R, \alpha x^G + (1-\alpha)a^G)]. \quad \blacksquare
\end{aligned}
$$

Proof of Proposition 7. Fix $u(\cdot)$ and ξ such that $u(1) - u(0) < \xi < u(0) - u(-1)$. This is possible since u is strictly concave. Let $\lambda = \alpha = \mu^R = 1 - \epsilon$, with $\epsilon > 0$. For sufficiently small ϵ, $\langle x^R, x^G \rangle = \langle 1,0 \rangle$ is a steady state:

$$
\begin{aligned}
\lim_{\epsilon \to 0} W\left(x^R \middle| \tilde{\delta} = \frac{\delta\mu^R}{1-\delta\mu^G}\right) &= W(x^R|\tilde{\delta} = \delta) \\
&= \frac{u(0)}{1-\delta} \quad \text{since } \frac{u(0)}{1-\delta} > \frac{u(-1)+\xi}{1-\delta} \\
\lim_{\epsilon \to 0} W\left(x^G \middle| \tilde{\delta} = \frac{\delta\mu^G}{1-\delta\mu^R}\right) &= W(x^G|\tilde{\delta} = 0) = u(0) + \xi \\
&\qquad \text{since } u(0) + \xi > u(1).
\end{aligned}
$$

A cue-management decision to permanently set the cue *GREEN* (starting from steady state $\langle x^R, x^G \rangle = \langle 1,0 \rangle$) yields future payoffs of $(u(0) + \xi)/(1 - \delta)$. And $\lim_{\epsilon \to 0} V(x^R, x^G) = u(0)/(1-\delta)$. This proves the main claim of the proposition.

The final claim in Proposition 7 can be shown by noting that of the four possible steady states, ($\langle x^R, x^G \rangle = \{\langle 0,0 \rangle, \langle 1,0 \rangle, \langle 0,1 \rangle, \langle 1,1 \rangle\}$), the consumer gains nothing by controlling the cue process when she is in either the first or last steady state. WLOG assume that the consumer is in steady state $\langle 1,0 \rangle$. The best cue-management decision that the consumer can take is to permanently set the cue *GREEN*. This yields a change in welfare of

$$
\begin{aligned}
&\frac{u(0)+\xi}{1-\delta} - V(1,0) \\
&\quad = \frac{u(0)+\xi}{1-\delta} - \frac{\mu^R}{1-\delta\mu^G} W\left(x^R \middle| \tilde{\delta} = \frac{\delta\mu^R}{1-\delta\mu^G}\right) \\
&\qquad - \frac{\mu^G}{1-\delta\mu^R} W\left(x^G \middle| \tilde{\delta} = \frac{\delta\mu^G}{1-\delta\mu^R}\right) \\
&\quad = \frac{u(0)+\xi}{1-\delta} - \frac{\mu^R u(1-\lambda) + (1-\mu^R)(u(0)+\xi)}{1-\delta} \\
&\quad = \frac{\mu^R[u(0)+\xi-u(1-\lambda)]}{1-\delta} < \frac{\xi}{1-\delta}.
\end{aligned}
$$

The last inequality follows from the fact that $u(0) + \xi - u(1 - \lambda) > 0$ (which is a necessary condition for existence of the $\langle 1,0 \rangle$ steady state), and $u(0) < u(1 - \lambda)$ (which follows from monotonicity of u, and $0 < \lambda < 1$). ■

DEPARTMENT OF ECONOMICS,
HARVARD UNIVERSITY

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