From Neuroscience to Public Policy: A New Economic View of Addiction*

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Abstract

A growing consensus in neuroscience regarding how addictive substances affect the brain supports the view that the consumption of addictive substances is sometimes rational, and sometimes a cue-triggered mistake. Neuroscientists have gained considerable insight into the specific processes that appear responsible for decision-making malfunctions involving addictive substances, and into the conditions under which these malfunctions occur. These insights lead to a new economic theory of addiction that bridges the gap between neuroscience and public policy. While the theory identifies a potential role for Draconian policies such as criminalization, it explicitly cautions against strategies that tend to magnify economic burdens on those who become addicted, and underscores the benefits of policies that reduce these burdens. For example, it suggests that, even when addictive substances are consumed to excess, "sin taxes" are counterproductive in identifiable circumstances. It also places a high value on policies that increase the likelihood of successful self-regulation without making particular choices compulsory, and it identifies a central role for "cognitive" policies, including the suppression of certain environmental cues (e.g., through limitations on advertising), and the dissemination of counter-cues.

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1 Introduction

Although more than four million chemical compounds have been catalogued to date, only a few score are classified as addictive by clinical consensus (Gardner and David (1999)). These include alcohol, barbiturates, amphetamines, cocaine, caffeine and related methylxanthine stimulants, cannabis, hallucinogens, nicotine, opioids, dissociative anesthetics, and volatile solvents. There is also some debate as to whether other substances, such as fats and sugars, or activities, such as shopping, shoplifting, sex, television viewing, and internet use, can also be classified as clinically addictive.

The consumption of these addictive substances raises important social issues affecting members of all socioeconomic strata, and citizens of virtually every nation. Readily available statistics for the United States illustrate the scope of the phenomenon.[1] Estimates for 1999 place total expenditures on tobacco products, alcoholic beverages, cocaine, heroin, marijuana, and methamphetamines at more than $150 billion. During a single month in 1999, more than 57 million individuals smoked at least one cigarette, more than 41 million engaged in binge drinking (involving five or more drinks on one occasion), and roughly 12 million used marijuana. In 1998, slightly more than 5 million Americans qualified as "hard-core" chronic drug users. Roughly 4.6 million persons in the workforce met the criterion for a diagnosis of drug dependence and 24.5 million had a history of clinical alcohol dependence. In 1998, additional social costs resulting from health care expenditures, loss of life, impaired productivity, motor vehicle accidents, crime, law enforcement, and welfare totalled $185 billion for alcohol and $143 billion for other addictive substances. Smoking killed roughly 418,000 people in 1990, alcohol accounted for 107,400 deaths in 1992, and drug use resulted in 19,277 deaths during 1998. Alcohol abuse contributed to 25 to 30 percent of violent crimes.

Even within countries, public policy toward various addictive substances is far from uniform, despite the commonalities suggested by their shared clinical classification. Policies range from laissez faire to taxation, subsidization (e.g. of rehabilitation programs), regulated dispensation, criminalization, product liability, and public health campaigns. Each alternative policy approach has passionate advocates and detractors.

Despite sharp disagreements about the ideal treatment of addictive substances, there is reasonably widespread agreement that most existing policies work poorly. The U.S. "War on Drugs" is, for example, often labeled a "failed policy." Use of banned substances remains widespread, and the resulting health costs are high. Prohibitions

[1] The statistics in this paragraph were obtained from the following sources: Office of National Drug Control Policy [2001a,b], U.S. Census Bureau [2001], National Institute on Drug Abuse [1998], National Institute on Alcohol Abuse and Alcoholism [2001], and Center for Disease Control [1993]. There is, of course, disagreement as to many of the reported figures.

on certain substances, like marijuana, lack credibility among younger Americans, who fail to see why alcohol and tobacco are singled out as socially acceptable. While the incidence of criminal activity among drug addicts is relatively high, it is important to acknowledge that drug related-crime is, to a significant extent, a consequence of current policy, rather than a justification for it. Criminalization promotes black markets, which fosters organized crime, and contributes to a culture of violence and prostitution. As a result, more than 625,000 citizens were incarcerated for drug-related offenses curing 1999. These people were disproportionately poor, black, and among society's most economically vulnerable members.

While existing policies have serious drawbacks, alternatives are also potentially problematic. For example, the high incidence of alcohol abuse and smoking, along with the attendant social costs, raise serious concerns about the potential consequences of across-the-board legalization. The apparent intractability of social problems related to addiction underscores the importance of creatively and openly rethinking policy strategies.

In this paper, we argue that recent advances in our understanding of the neural basis of addiction has critical implications for public policy. This research supports the view that the consumption of addictive substances is sometimes rational, and sometimes a mistake. Neuroscientists have gained considerable insight into the specific processes that appear responsible for decision-making malfunctions involving addictive substances, and into the conditions under which these malfunctions occur. These insights lead to a new behavioral theory of addiction, which we have developed in Bernheim and Rangel [2004]. This theory allows us to bridge the gap between neuroscience and public policy. While it identifies a potential role for Draconian policies such as criminalization, it explicitly cautions against strategies that tend to magnify economic burdens on those who become addicted, and underscores the benefits of policies that reduce these burdens. For example, contrary to another leading behavioral theory of addiction (see, e.g., Gruber and Koszegi [2001] and O'Donohue and Rabin [2000]), ours suggests that, even for addictive substances that are consumed to excess, "sin taxes" are counterproductive in some identifiable and empirically relevant circumstances. It also places a high value on policies that improve opportunities for self-regulation without making particular choices compulsory, and it identifies a central role for "cognitive" policies, including the suppression of certain environmental cues (e.g., through limitations on advertising), and the dissemination of counter-cues.

There is significant overlap between this paper and Bernheim and Rangel [2004]. However, unlike its predecessor, the current paper is intended for a general policy audience. It emphasizes the main ideas of our theory and avoids technical details. It also goes beyond our earlier work by presenting numerical simulation results for an extended version of the model. These simulations, while preliminary, provide a sense for the quantitative importance of the effects emphasized in the theory, and it provides a general sense for the features of optimal public policy.

The paper is organized as follows. In Section 2, we discuss the nature of addiction from the perspective of behavior. In Section 3, we focus on the nature of addiction from the perspective of neuroscience. In Section 4, we summarize a new economic view of addiction that is motivated by research from neuroscience, and by the behavioral evidence. Section 5 concerns standards and criteria for policy evaluation. Section 6 discusses policy implications, and contains illustrative simulations. Section 7 concludes.

2 What is Addiction? A Behavioral Perspective

According to clinical definitions, substance addiction occurs when, after significant exposure, users find themselves engaging in compulsive, repeated, and unwanted use despite clearly harmful consequences, and often despite a strong desire to quit unconditionally (see e.g. the American Psychological Association's Diagnostic and Statistical Manual of Mental Disorders, known as DSM-IV). A critical feature of this definition involves the notion of mistakes or unwanted consumption. This anticipates one of the central issues addressed in this paper: under what conditions should public policy makers explicitly recognize the principle that voluntary actions may be ill-considered? We will turn to this question in the next section.

In some ways, consumption patterns for addictive substances are no different than for other goods. A number of studies have shown that aggregate drug use responds both to prices and to information about the effects of addictive substances. For example, an aggressive U.S. public health campaign is widely credited with reductions in smoking rates. There is also evidence that users engage in sophisticated forward-looking deliberation, reducing current consumption in response to anticipated price increases.[2]

What, then, makes addiction a distinctive phenomenon? From the extensive body of research on addiction in neuroscience, psychology, and clinical practice, we have distilled five important behavioral patterns.

1. *Unsuccessful attempts to quit.* Addicts often express a desire to stop using a substance permanently and unconditionally but are unable to follow through. Short-term abstention is common while long-term recidivism rates are high. For example, during 2000, 70 percent of current smokers expressed a desire to quit *completely* and 41 percent stopped smoking for at least one day in an attempt to quit, but only 4.7

[2]See Chaloupka and Warner [2001], MacCoun and Reuter [2001], and Gruber and Koszegi [2001] for a review of the evidence.

percent successfully abstained for more than three months.[3] This pattern is particularly striking because regular users initially experience painful withdrawal symptoms when they first attempt to quit, and these symptoms decline over time with successful abstention. Thus, recidivism often occurs after users have borne the most significant costs of quitting, sometimes following years of determined abstention.

2. *Cue-triggered recidivism.* Recidivism rates are especially high when addicts are exposed to cues related to past drug consumption. Long-term usage is considerably lower among those who experience significant changes of environment.[4] Treatment programs often advise recovering addicts to move to new locations and to avoid the places where previous consumption took place. Stress and "priming" (exposure to a small taste of the substance) have also been shown to trigger recidivism.[5]

3. *Self-described mistakes.* Addicts often describe past use as a mistake in a very strong sense: they think that they would have been better off in *the past as well as the present* had they acted differently. They recognize that they are likely to make similar errors in the future, and that this will undermine their desire to abstain. When they succumb to cravings, they sometimes characterize choices as mistakes *even while in the act of consumption.* It is instructive that the twelve-step program of Alcoholic Anonymous begins: "We admit we are powerless over alcohol - that our lives have become unmanageable."

As an example, Goldstein [2001,p.249] describes an addict who had been

> "...suddenly overwhelmed by an irresistible craving, and he had rushed out of his house to find some heroin. ... it was as though he were driven by some external force he was powerless to resist, *even though he knew while it was happening that it was a disastrous course of action for him*" (italics added).

4. *Self-control through precommitment.* Recovering users often manage their tendency to make mistakes by voluntarily removing or degrading future options. They voluntarily admit themselves into "lock-up" rehabilitation facilities, often not to avoid cravings, but precisely because they expect to experience cravings and wish to control their actions. They also consume medications that either generate unpleasant side

[3] See Trosclair et. al. [2002], Goldstein [2001], Hser, Anglin, and Powers [1993], Harris [1993], and O'Brien [1997].

[4] See Goldstein [2001], Goldstein and Kalant [1990], O'Brien [1976,1997], and Hser et. al. [1993,2001]. Robins [1994] and Robins et.al. [1974] found that Vietnam veterans who were addicted to heroin and/or opium at the end of the war experienced much lower relapse rates than other young male addicts during the same period. A plausible explanation is that veterans encountered fewer environmental triggers (familiar circumstances associated with drug use) upon returning to the U.S.

[5] See Goldstein [2001] and Robinson and Berridge [2003].

effects, or reduce pleasurable sensations, if the substance is subsequently consumed.[6] Severe addicts sometimes enlist others to assist with physical confinement to assure abstinence through the withdrawal process.

5. *Self-control through behavioral and cognitive therapy.* Recovering addicts attempt to minimize the probability of relapse through behavioral and cognitive therapies. Successful behavioral therapies teach cue-avoidance, often by encouraging the adoption of new life-styles and the development of new relationships and interests. Successful cognitive therapies teach cue-management, which entails refocusing attention on alternative consequences and objectives, often with the assistance of a mentor or trusted friend or through a meditative activity such as prayer. Notably, these therapeutic strategies affect addict's choices *without providing new information*.[7]

From the perspective of traditional economic analysis, each of these patterns is somewhat puzzling. The rational consumers of economic textbooks have no trouble following through on plans. By assumption, they always choose what they want, so, armed with good information, they can't make systematic mistakes. The notion that someone might be powerless over a consumption good is anathema to a neoclassical economist. The standard economic theory of consumer behavior embraces the principle that expanding or improving the set of available alternatives necessarily makes an individual better off, so precommitments can only be counterproductive. Serious consideration of addictive behaviors therefore forces us to think "outside the box."

It is important to remember that consumption patterns for the typical addictive substance vary considerably from person to person.[8] Some people never use it. Some use it in a controlled way, either periodically or for a short time period. Some experience occasional episodes where they appear to "lose control" (binge), but suffer no significant ongoing impairment, and have no desire to quit permanently. Some fit the DSM-IV definition of addiction. In the rest of the paper the term *addict* is reserved for the third and fourth groups, whereas the term *user* is applied to everyone.

[6] Disulfiram interferes with the liver's ability to metabolize alcohol; as a result, ingestion of alcohol produces a highly unpleasant physical reaction for a period of time. Methadone, an agonist, activates the same opioid receptors as heroin, and thus produces a mild high, but has a slow-onset and a long-lasting effect, and it reduces the high produced by heroin. Naltrexone, an antagonist, blocks specific brain receptors, and thereby diminishes the high produced by opioids. All of these treatments reduce the frequency of relapse. See O'Brien [1997] and Goldstein [2001].

[7] Goldstein [2001] reports that there is a shared impression among the professional community that 12-step programs such as AA (p. 149) "are effective for many (if not most) alcohol addicts." However, given the nature of these programs, objective performance tests are not available. The AA treatment philosophy is based on "keeping it simple by putting the focus on not drinking, on attending meetings, and on reaching out to other alcoholics."

[8] Even for a a substance such as cocaine, which is considered highly addictive, only 15-16 percent of people become addicted within 10 years of first use (Wagner and Anthony [2002]).

3 What is Addiction? A Perspective from Neuroscience

Recent advances in the neuroscience of addiction provide a solid foundation for understanding addiction as a malfunction of the brain's decision making circuitry. We divide our discussion of the pertinent evidence into two parts. First we provide a general overview of the central ideas, and then we discuss the foundations for these ideas in some detail.

3.1 An overview of the central ideas

Prior to the 1990s, neurological theories of addiction were based on some form of the pleasure principle. It was widely believed that people start using drugs to achieve a pleasurable "high," and continue using them despite deterioration of the high (a phenomenon known as "hedonic tolerance") to avoid unpleasant feelings, including cravings and withdrawal. Economists refer to these sensations of pleasure and pain as "hedonic" effects.

Over the last 10 years, a new scientific consensus has begun to emerge concerning the neural basis of addiction. Neuroscientists continue to believe that addictive substances have the hedonic effects described above. However, it now appears that hedonic effects are not the central part of the story. This new view holds that effects on decision processes, rather than on pleasure, hold the key to understanding addictive behavior. This is not to say that pleasure plays no role; obviously it does. However, there is also a precise sense in which addictive substances sometimes cause decision processes to malfunction.

Figure 1 shows, at a high level of abstraction, how the brain makes decisions about standard consumption goods. Our senses provide us with information about environmental conditions and internal states – things like hunger, fatigue, and so forth. Our brain uses multiple processes to analyze the desirability of different options in the presence of these states, which results in a decision. The decision is followed by an experience, including rewards. The experienced relationship between environmental conditions, decisions, and rewards modifies our decision-making processes, an effect known as learning.

On left-hand side of this diagram, we've highlighted one particular decision-making process, which we've labeled the hedonic forecasting mechanism (HFM).[9] The brain appears to have a variety of mechanisms for forecasting the possible consequences of decisions. Some involve higher cognition; for example, we sometimes develop causal

[9]The phrase "hedonic forecasting mechanism" summarizes the role of this process in economic terms; this terminology is not used in the existing behavioral neuroscience literature.

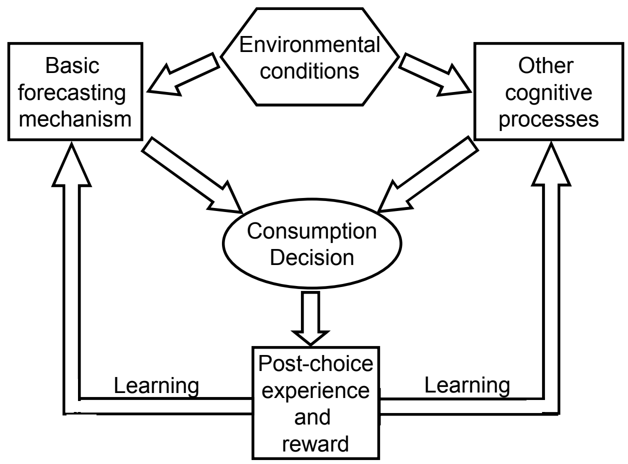

Figure 1: Decision processes for standard consumption goods

models of the world and reason out the implications of our actions. Some are more mechanical. The basic forecasting mechanism is a simple system for learning correlations between current conditions, decisions, and short-term rewards. It does not involve higher reasoning; in fact, it's present in lower life forms as well as humans.

Sometimes we act solely based on the evaluations (or forecasts) generated by the basic forecasting mechanism, which might be experienced subjectively as "gut feelings." Sometimes higher cognitive processes override the evaluations of the basic forecasting mechanism, a phenomenon known as cognitive control.

Each process has it's advantages and disadvantages. The basic forecasting mechanism is very fast and efficient at learning simple action-reward correlations, but it's inflexible and unsophisticated in the sense that it can only learn about a limited range of near-term consequences. Higher cognition is more flexible and sophisticated, but it is comparatively slow, and also has limited learning capabilities. When we have to make decisions very quickly, we rely on our gut reactions. When there's no time pressure, we take the time to think things through. A balance between these systems emerged through evolution as nature's best compromise.

Importantly, the mere fact that we rely in some instances on impulses and gut reactions, rather than reasoned deliberation, does not mean that our choices are irrational

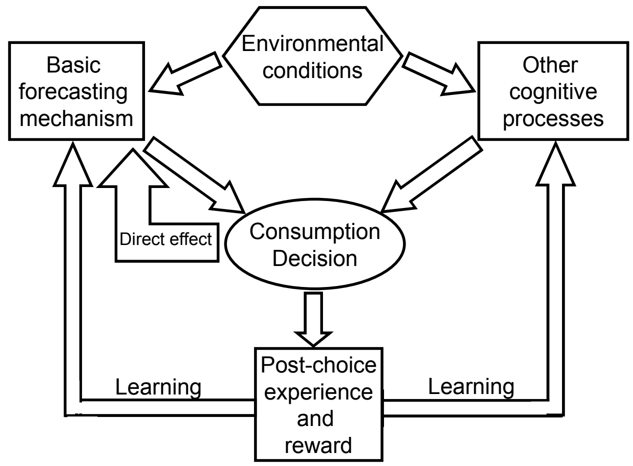

Figure 2: Decision processes for addictive substances

or dysfunctional. The evaluations of the basic forecasting mechanism often lead to appropriate choices. Furthermore, a growing body of research suggests that the basic hedonic forecasting mechanism is essential for good decision-making, in the sense that, when this mechanism is impaired (for example, by localized brain lesions), people have difficulty making even relatively simple choices (see Bechara and Damasio [2005] for a recent review of this literature).

The growing consensus in neuroscience is that addiction results from the impact that the addictive substances have on the HFM. Normally, the HFM learns through feedback from the hedonic system: with experience, it associates a situation and action with an anticipatory response, the magnitude of which reflects the intensity of expected pleasure. Addictive substances interfere with the normal operation of the HFM by acting *directly* (i.e., independent of the pleasure experienced) on the process that leads the HFM to generate the anticipatory response. With repeated use of a substance, cues associated with past consumption cause the HFM to forecast grossly exaggerated pleasure responses, creating a powerful (and disproportionate) impulse to use. When this happens, a portion of the user's decision processes functions as if it has systematically skewed information, which leads to mistakes in decision making.

A comparison between Figures 1 and 2 illustrates the problem. The addictive substances act directly on the HFM, short-circuiting the neurological process by which this mechanism measures correlations between environmental conditions, decisions, and rewards. As a result, the mechanism massively overstates the correlation between drug use and actual experienced pleasure. Subjectively, this effect manifests itself through intense wanting, or cravings. Loosely, drugs fool a subconscious, hard-wired brain process into anticipating an exaggerated level of pleasure. An addict can try to *compensate* for this effect by exercising cognitive control, but he can't consciously *correct* it.

The preceding discussion implies that, in some circumstances, drug use can literally be a mistake, in the sense that the brain is fooled into making a choice. It does *not*, however, imply that drug use is *always* a mistake. Even if the integrity of the basic forecasting mechanism is compromised, higher cognition can still either agree with it or override it. In different people, brain chemistry appears to strike different balances between these mechanisms. This may explain why some people become addicts, while others use repeatedly without becoming addicted. Use can be rational in some instances and irrational in others. It is important to bear this point in mind when evaluating public policies alternatives.

3.2 Some details

In the remainder of this section, we describe some of the key evidence that leads to these conclusions. We organize our discussion around four points.

1. *The brain's decision-making processes include a hedonic forecasting mechanism (HFM) which, with experience, produces a response to situations and opportunities, the magnitude of which constitutes a forecast of near-term pleasure*. Neuroscientists have long recognized that the mesolimbic dopamine system (MDS) is a basic component of human decision processes.[10] A large body of recent research indicates that the MDS functions, at least in part, as an HFM. In a series of experiments, subjects (often monkeys) are presented with a cue that is associated with a reward delivered a few seconds later (see Schultz, Dayan, and Montague [1997] and Schultz [1998, 2000]). Initially, the MDS fires in response to the delivery of the reward and not in response to the cue. However, as time passes, the MDS fires with the presentation of the cue and not with the delivery of the reward. Moreover, the level of cue-triggered MDS activity is proportional to the size of the eventual reward. If, after a number of trials, the experimenter increases the magnitude of the reward, the MDS fires twice: with

[10]The MDS originates in the ventral tegmental area, near the base of the brain, and sends projections to multiple regions of the frontal cortex, especially to the nucleus accumbens. The MDS also connects with the amygdala, basal forebrain, and other areas of the prefrontal cortex. These connections are believed to serve as an interface between the MDS and attentional, learning, and cognitive processes (Robinson and Berridge [2003]).

the presentation of the cue (at a level proportional to the original anticipated reward), and with the delivery of the reward (at a level reflecting the difference between the anticipated and actual rewards). After repeated trials with the new reward, the MDS fires more intensely upon presentation of the cue and, once again, does not respond to the delivery of the reward. Thus, with experience the MDS generates a cue-conditioned dopamine response that anticipates the magnitude of the eventual reward.

2. *Activation of the HFM does not necessarily create hedonic sensation, and hedonic sensation can be experienced without HFM activation.* Since the MDS produces a dopamine response prior to an anticipated experience and no response during the experience, it is natural to conjecture that this mechanism is neither a source nor a manifestation of pleasure. Indeed, the human brain appears to contain a separate hedonic system that is responsible for producing sensations of 'well-being.'[11] In a series of papers, neuroscientists Kent Berridge and Terry Robinson have argued that two separate processes are at work in decision making: a "wanting" process, which encompasses the impulse created by a positive MDS forecast, and a "liking" process, which refers to a hedonic response (see Berridge[1996,1999], Berridge and Robinson [1998,2003], and Robinson and Berridge [1993,2000,2003]).[12] Their hypothesis emerges from numerous experimental studies, including the following. Using measures of 'liking' based on rats' facial expressions when responding to sweet and sour tastes, several experiments have shown that neither the direct activation of the MDS, nor its suppression, affects liking (Wyvell and Berridge [2000], Pecina et. al. [1997] and Kaczmarek and Kiefer [2000]). Others have demonstrated that the 'liking' system functions well even with massive lesions to the MDS (see Berridge and Robinson [1998]). Direct activation of the MDS through microinjections of amphetamine in the nucleus accumbens (NAc) increases wanting but fails to increase liking (Wyvell and Robinson [2000]). Finally, blocking the MDS with dopamine antagonists does not have an impact on the level of pleasure obtained from using a drug reported by amphetamine and nicotine users (Brauer et. al. [1997,2001] and Wachtel et. al. [2002]).

3. *HFM-generated forecasts influence choices.* A series of classic experiments by Olds and Milner [1954] demonstrated that rats learn to return to locations where they have received direct electrical stimulation to the MDS. When provided with opportunities to self-administer by pressing a lever, the rats rapidly became addicted, giving themselves approximately 5,000-10,000 "hits" during each one hour daily session, ig-

[11]The existing evidence suggests that the hedonic system is modulated in a distributed network, separate from the structures involved in the HFM, that includes GABAergic neurons in the shell of the NAc, the ventral palladium and the brainstem parachial nucleus (see Berridge and Robinson [2003]).

[12]For decades, neuroscientists and psychologists have used the term "reward" to describe both liking and wanting. In most experimental settings, the distinction is immaterial since outcomes that are liked are also wanted, and vice versa. However, as we will see, this distinction is critical to understanding why repeated exposure to drugs leads to mistaken usage.

noring food, water, and opportunities to mate. These rats are willing to endure painful electric shocks to reach the lever (see Gardner and David [1999] for a summary of these experiments). Complementary evidence shows that rats who are given drugs that block dopamine receptors, thereby impeding the appropriate operation of the MDS, eventually stop feeding (Berridge [1999]).

Notably, the MDS activates "seeking behaviors" as well as immediate consumption choices. That is, it learns to make associations not just between consumption opportunities and hedonic payoffs, but also between environmental cues and activities that tend to produce these consumption opportunities. For example, the sight of food may create a powerful impulse to eat, while an odor may create a powerful impulse to seek food. The size of the set of environmental cues that trigger an associated seeking behavior increases with the strength of the hedonic forecast (see Berridge and Robinson [1998,2003] and Robinson and Berridge [1993,2000,2003])).

While the MDS plays a key role in determining choices, it is not the only process at work. In an organism with a sufficiently developed frontal cortex, higher cognitive mechanisms can override HFM-generated impulses. Though the specific mechanisms are not yet fully understood, structures in the frontal cortex appear to activate competing 'cognitive incentives' (Berridge and Robinson [2003]), for example by identifying alternative courses of action or projecting the future consequences of choices. The outcome depends on the intensity of the HFM forecast and on the ability of the frontal cortex to engage the necessary cognitive operations.[13] Thus, a more attractive HFM-generated forecast makes cognitive override less likely. In addition, the MDS also seems to affect which stimuli the brain attends to, which cognitive operations it activates (what it thinks about), and which memories it preserves, and this may make it more difficult to engage the cognitive operations required to override the HFM.[14]

We emphasize that the HFM and higher cognitive processes are not two different sets of "preferences" or "selves" competing for control of decisions. Hedonic experiences are generated separately, and an individual maximizes the quality of these experiences by appropriately deploying both forecasting processes to anticipate outcomes. The HFM's main advantage is that it can produce rapid decisions with generally beneficial near-term outcomes provided the environment is stable. It cannot, however, anticipate sufficiently delayed consequences, and when the environment changes, it can neither ignore irrelevant past experiences nor adjust forecasts prior to acquiring further experience. The competing cognitive forecasting system addresses these shortcomings

[13] The activation of the cognitive representations required for cognitive control depends on neocortical structures such as the insula and the orbitofrontal cortex (see e.g. Krawcyzk [2002], Rolls [2000], Watanabe et. al. [2002], and Cohen and Blum [2002])

[14] Notably, more educated individuals are far more likely to quit smoking successfully, even though education bears little relation either to the desire to quit or to the frequency with which smokers attempt to quit (Trosclair et. al. [2002]).

(albeit imperfectly), but is comparatively slow. Balanced competition between these two processes apparently emerged as evolution's best compromise.

4. *Addictive substances act directly on the HFM, disrupting its ability to construct accurate hedonic forecasts and exaggerating the anticipated hedonic benefits of consumption.* Although addictive substances differ considerably in their chemical and psychological properties, there is a large and growing consensus in neuroscience that they share an ability to activate the firing of dopamine into the NAc with much greater intensity and persistence than other substances. They do this either by activating the MDS directly, or by activating other networks that have a similar effect on the NAc (see Nestler and Malenka [2004], Hyman and Malenka [2001], Nestler [2001], Wickelgreen [1997], and Robinson and Berridge [2003]).[15]

For non-addictive substances, the MDS learns to assign a hedonic forecast that bears some normal relation to the subsequent hedonic experience. For addictive substances, consumption activates dopamine firing directly, so the MDS learns to assign a hedonic forecast that is out of proportion to the subsequent hedonic experience. This not only creates a strong (and misleading) impulse to seek and use the substance, but also undermines the potential for cognitive override.[16] Cognitive override still occurs, but in a limited range of circumstances.[17,18]

[15]Of the addictive substances listed in footnote 1, only hallucinogenics (or psychedelics) do not appear to produce intense stimulation of the MDS. Instead, they act on a "subtype of serotonin receptor which is widely distributed in areas of the brain that process sensory inputs" (Goldstein [2001, p.231]). There is some disagreement as to whether hallucinogens are properly classified as addictive substances (see Goldstein [2001, ch. 14]). Notably, laboratory animals and humans learn to self-administer the same set of substances, with the possible exception of hallucinogenics (Gardner and David [1999, p.97-98]).

[16]A stronger MDS-generated impulse is more likely to overcome competing cognitive incentives of any given magnitude. In addition, the MDS-generated impulse may make it more difficult to engage the cognitive operations required to override the HFM. For example, recovering addicts may pay too much attention to drugs, activate and mantain thoughts about the drug too easily, and retain particularly vivid memories of the high. Consistent with this, Vorel et. al. [2001] have shown that the stimulation of memory centers can trigger strong cravings and recidivism among rats that have previously self-administered cocaine (Vorel and Gardner [2001] and Holden [2001a,b] provide non-technical discussions).

[17]The importance of cognitive override is evident from comparisons of rats and humans. When rats are allowed to self-administer cocaine, after a short period of exposure they begin to ignore hunger, reproductive urges, and all other drives, consuming the substance until they die (Pickens and Harris [1968] and Gardner and David [1999]). In contrast, even severely addicted humans sometimes resist cravings and abstain for long periods of time. The difference is that rats rely solely on the HFM.

[18]Several studies (see Bolla et. al. [1998], Robbins and Everett [1999], Bechara and Damasion [2002a,b], and Jentsch and Taylor [1999]) have shown that addicts share psychological disorders with patients who have damaged frontal lobes affecting functions related to cognitive control. In addition, some of these studies have argued that drug use is partly responsible for this impairment. Thus, use may increase the likelihood of subsequent use by crippling cognitive control mechanisms.

3.3 Other effects of addictive substances

In emphasizing the effects of addictive substances on decision processes, we do not mean to discount the significance of their hedonic effects. The typical user is initially drawn to an addictive substance because it produces a hedonic "high." Over time, regular use leads to hedonic and physical tolerance. That is, the drug loses its ability to produce a high unless the user abstains for a while,[19] and any attempt to discontinue the drug may have unpleasant side effects (withdrawal). Cue-conditioned "cravings" may have hedonic implications as well as non-hedonic causes (i.e. HFM-generated impulses). All of these effects are clearly important. However, there is an emerging consensus in neuroscience and psychology that decision-process effects, rather than hedonic effects, provide the key to understanding addictive behavior (see Wise [1989], Robbins and Everitt [1996], Di Chiara [1999], Kelley [1999], Nestler and Malenka [2004], Hyman and Malenka [2001], Berridge and Robinson [2003], Robinson and Berridge [2000], and Redish [2004]).

4 What is Addiction: A New Economic View

In Bernheim and Rangel [2004], we develop a new economic theory of addiction that is based on the neuroscience view of the phenomena described above. The model is based on the following three main premises:

First, use among addicts is *sometimes* a mistake, in the sense that actions diverge from preferences. It is also sometimes rational. We justify this premise with reference to the research, summarized above, which shows that addictive substances undermine the proper operation of the hedonic forecasting mechanism.

Second, experience with an addictive substance sensitizes an individual to environmental cues that trigger mistaken usage. We justify this premise with reference to the same body of research, which shows that, through experience, the brain tends to make skewed hedonic forecasts after encountering environmental stimuli that are correlated with past substance use.

Third, addicts understand their susceptibility to cue-triggered mistakes and attempt to manage the process with some degree of sophistication. We justify this premise with reference to behavioral evidence indicating that users of addictive substances are often surprisingly sophisticated and forward looking. For example, they reduce current consumption in response to expected future price increases (Gruber and Koszegi

[19] According to one user-oriented website, tolerance to marijuana "builds up rapidly after a few doses and disappears rapidly after a couple of days of abstinence. Heavy users need as much as eight times higher doses to achieve the same psychoactive effects as regular users using smaller amounts. They still get stoned but not as powerfully" (see htpp://www.thegooddrugsguide.com/cannabis/addiction.htm.)

[2001]). Some particularly skilled users also enter detox not because they intend to remain sober, but rather because they want to increase the intensity of the next high.

4.1 The Model

Using these principles as a starting point, we develop a mathematical model of decision-making, which we summarize here in words (see Bernheim and Rangel [2004] for technical details).[20] The model depicts an individual who makes a sequence of decisions regarding lifestyle (e.g., going to a bar or staying home), the use of an addictive substance, and the consumption of non-addictive substances. The model assumes that, at any point in time, the individual operates in one of two modes: a "cold" mode in which he selects his most preferred alternative (if necessary, by imposing cognitive control), and a dysfunctional "hot" mode in which decisions and preferences may diverge (because he responds to distorted HFM-generated forecasts).[21] The hot mode is transient, but always results in use of the substance. The likelihood of entering the hot mode at any moment depends on the individual's history of substance use, his chosen lifestyle, and random events (e.g. the frequency and intensity of recently encountered environmental cues to which he has been sensitized through prior use).

We summarize the history of use through the notion of an *addictive state*. With some probability, use moves the individual to a more highly addictive state, and abstention moves him to a less highly addictive state. We assume that an increase in the addictive state raises the likelihood of entering the hot mode at any moment (e.g., because it implies increased sensitivity to randomly occuring environment cues). Higher addictive states are also associated with lower baseline well-being (e.g., due to deteriorating health).

Enjoyable lifestyles entail higher probabilities of entering the hot mode (e.g., partying exposes the individual to more intense substance-related cues). The least enjoyable (and most costly) lifestyle choice is rehabilitation, which temporarily guarantees abstention (e.g. through clinical treatment at a residential center).

The individual has access to a flow of resources (income), but, for the sake of analytic tractability, cannot borrow or save. We assume that these resources decline with the

[20] The simulation model used here is slightly more complicated than the one describe in Bernheim and Rangel [2004]. First, it allows each decision to depend, in part, on a stochastic shock (representing a transient mood). As a result, decisions are probabilistic, instead of deterministic. Second, as described below, transitions between states, conditional on decisions, are probabilistic rather than deterministic.

[21] Our analysis is related to work by Loewenstein [1996, 1999], who considers simple models in which an individual can operate either in a hot or cold decision-making mode. Notably, Loewenstein assumes that behavior in the hot mode reflects the application of a "false" utility function, rather than a breakdown of the processes by which a utility function is maximized. He also argues, contrary to our findings, that imperfect self-understanding is necessary for addiction-like behaviors.

addictive state due to deteriorating health, reduced productivity (e.g. through absenteeism), and increased out-of-pocket medical expenses. Greater spending on addictive substances consumes resources, and therefore necessitates a reduction in spending on non-addictive goods. Both addictive and non-addictive goods are pleasurable, but the incremental "boost" from consuming the addictive substance rises with the addictive state. When evaluating the desirability of any possible set of current and future outcomes, the individual discounts future hedonic payoffs at a fixed rate.

By varying assumptions about the properties of the substance in question, the model can replicate a wide range of observed behaviors. In particular, it can account for each of the patterns discussed in Section 2 (see Bernheim and Rangel [2004] for details) and provide a qualitatively plausible mapping between the properties of substances and the consumption patterns that they generate. The next section illustrates this through numerical simulations.

4.2 Behavioral Simulations

Starting with the general model summarized in the last section, we make specific numerical assumptions about the characteristics of the substance and the user, and then computationally simulate the user's behavior. The following is a brief non-technical summary of our assumptions.

We consider an individual whose lifetime is divided into 2000 consecutive time periods. We think of each period as roughly a week, which means that total lifespan is 40 years. Income in the absence of any negative consequences from drug use is $800 per period (or roughly $40,000 per year). At any point in time, the individual is in one of fifty-one addictive states, including an initial "virgin" state. Use tends to increase the addictive state, and abstention tends to decrease it. In particular, if the individual uses while in state s, there is a 5 percent chance he enters the next period in state $s+1$, and a 95 percent chance he remains in state s. Likewise, if he abstains while in state s, there is a 5 percent chance he enters the next period in state $s-1$, and a 95 percent chance he remains in state s. With constant use, an individual would therefore move from state 0 to state 50 in 1000 periods (20 years), on average.

The addictive state affects the individual in four ways: it increases the hedonic "kick" from consuming the substance; it increases the likelihood that randomly occurring environmental cues will trigger unwanted use; it erodes baseline well-being (e.g., through deteriorating health), and it reduces available resources (e.g., through damaged earnings capacity and out-of-pocket medical expenses). The speed with which these effects materialize differs across substances, and, for a single substance, differs across effects. For example, addiction often develops quickly, while health problems emerge much later.

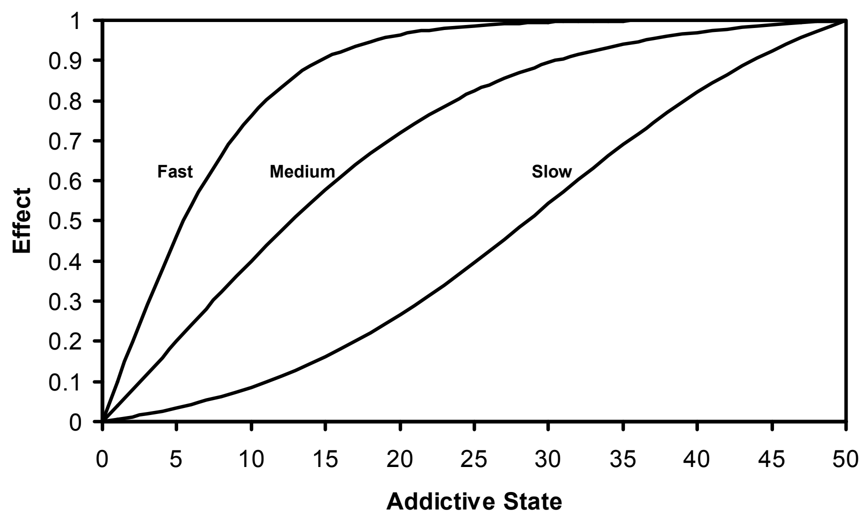

Figure 3: Speed of effects

In each simulation, we use one of three standardized patterns to describe how a given effect evolves with the addictive state. We illustrate these in Figure 3. For the curve labeled "fast," significant effects emerge almost immediately. More than 50 percent of the effect is present by the sixth addictive state, and more than 90 percent is present by the fifteenth state. For the curve labeled "slow," sizable effects do not emerge until reasonably advanced states. More than 50 percent of the effect is present by the 29th addictive state, and more than 90 percent is present by the forty-fourth state. The curve labeled "medium" provides an intermediate case: more than 50 percent of the effect is present by the thirteenth state, and more than 90 percent is present by the thirty-first.

For the simulations, we also distinguish between three possible lifestyle activities – "exposure" (e.g., attending a party at which the substance is present), "avoidance" (e.g., staying at home), and rehabilitation. Exposure is the most enjoyable and leads to the highest likelihood of unintended use. Avoidance is less enjoyable, but cuts the likelihood of unintended use in half. Rehabilitation is the least enjoyable, but guarantees abstention. In each period, the individual makes one of four choices: exposure and use, exposure and attempted abstention, avoidance and attempted abstention, and

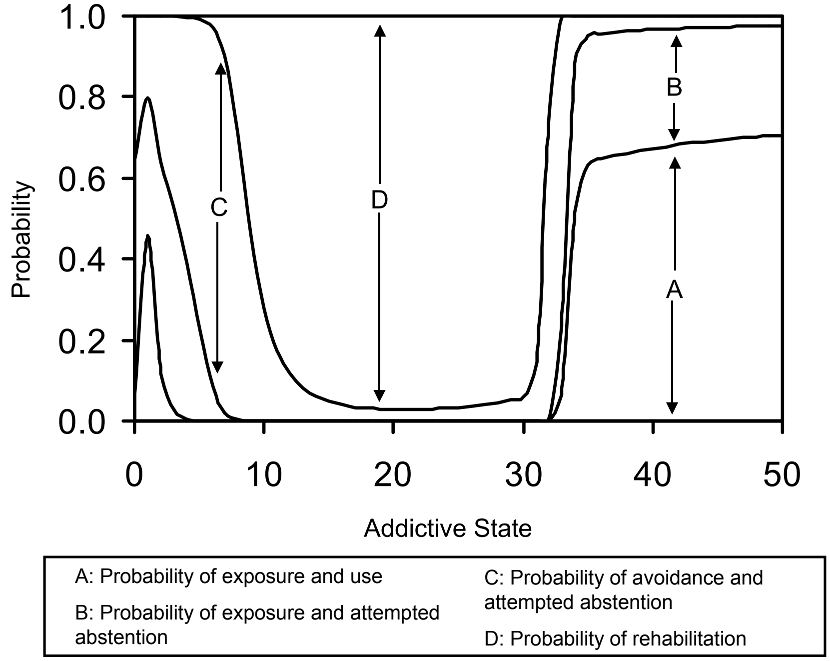

Figure 4: Optimal choices, by addictive state, for a heroin-like substance

rehabilitation.[22]

We consider two cases; one is intended to resemble heroin, and the other is intended to resemble cigarettes.

4.2.1 A case resembling heroin

To model behavioral patterns for a heroin-like substance, we assume that the onset of addictive effects (rising hedonic kick from consumption, and rising probability of cue-triggered use) is "fast," while the speed with which costs emerge (declining baseline well being, and deteriorating health) is moderate. In the case considered, the probability of unwanted, cue-triggered use rises to a maximum of 80 percent per week, the net hedonic benefit from use is sizable (four times as large as for cigarettes) and triples with use, the long-run impact on resources is substantial ($400 per period), as are the potential effects on baseline well-being (four times as large as for cigarettes). We assume that users spent $200 per period on the substance (based on estimates placing annual spending in excess of $10,000 per year). Rehabilitation costs $250 per period and involves a substantial utility penalty.

[22]He would never choose avoidance and use, since avoidance is less intrinsically desirable than exposure.

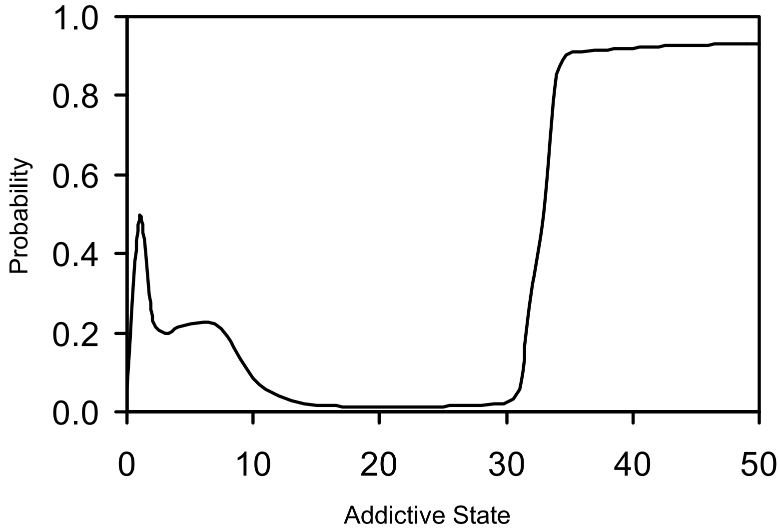

Figure 5: Probability of use, by addictive state, for a heroin-like substance

Figure 4 shows the probability, by addictive state, of making each of the four possible choices (exposure and use, exposure and attempted abstention, avoidance and attempted abstention, and rehabilitation). The lowest curve indicates the probability of selecting exposure and use. The difference between the lowest and second-lowest curves indicates the probability of selecting exposure and attempted abstention. The difference between the second-lowest and highest curves indicates the probability of avoidance. The difference between the highest curve and unity (that is, the top boundary of the graph) indicates the probability of rehabilitation. The graph shows that the individual chooses exposure at low addictive states. Between states 5 and 10, he shifts sharply to avoidance, and then to rehabilitation. Moderately addicted users (those between states 15 and 30) are very likely to enter rehabilitation. However, some continue consuming. Once they reach very highly addicted states, they resign themselves to addiction, engaging in avoidance only infrequently, and rarely attempting rehabilitation.

The probability of use in each addictive state, shown in Figure 5, depends both on the probability of each choice, and on the likelihood that each choice will lead to use. At low addictive states there is a moderate probability of use. As the state rises, this probability declines because the individual shifts to avoidance and then to

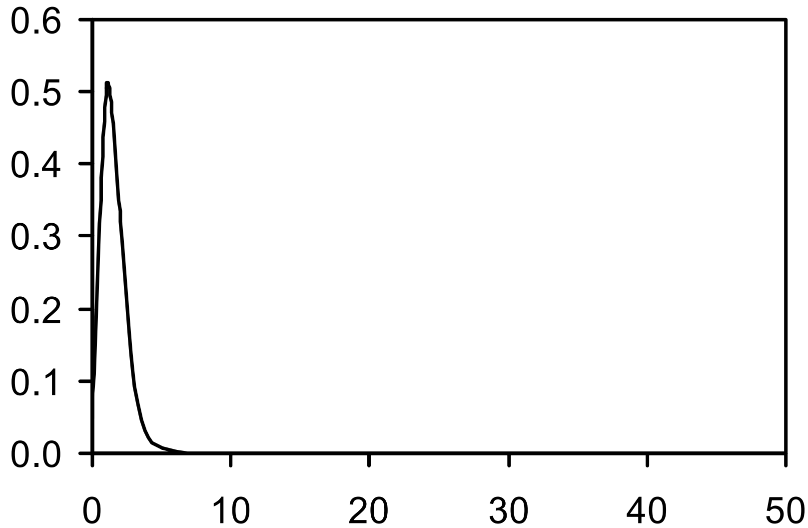

Figure 6: Population distribution, by state, after 20 years, for a heroin-like substance

rehabilitation. Beyond state 35, in the region of resignation, the likelihood of use is extremely high.

Figure 6 shows the distribution of the population across addictive states in period 1000 (that is, after 20 years). Through abstention and rehabilitation, most users remain in relatively low addictive states. However, a small number of unlucky consumers become highly addicted. (Though this is difficult to see due to the scale of the graph, the curve does not quite reach the horizontal axis.)

How does substance consumption respond to changes in price and income? We use our simulation model to calculate aggregate "steady state" elasticities in an economy with a sequence of equally sized overlapping generations. For this case, the price elasticity of demand is -0.97 (a one percent increase in price leads to a 0.97 percent reduction in the quantity consumed), and the income elasticity is 0.54 (a one percent increase in income leads to a 0.54 percent increase in the quantity consumed).

4.2.2 A case resembling cigarettes

To model behavioral patterns for a cigarette-like substance, we assume that the onset of addictive effects (rising net hedonic kick from consumption, and rising probability

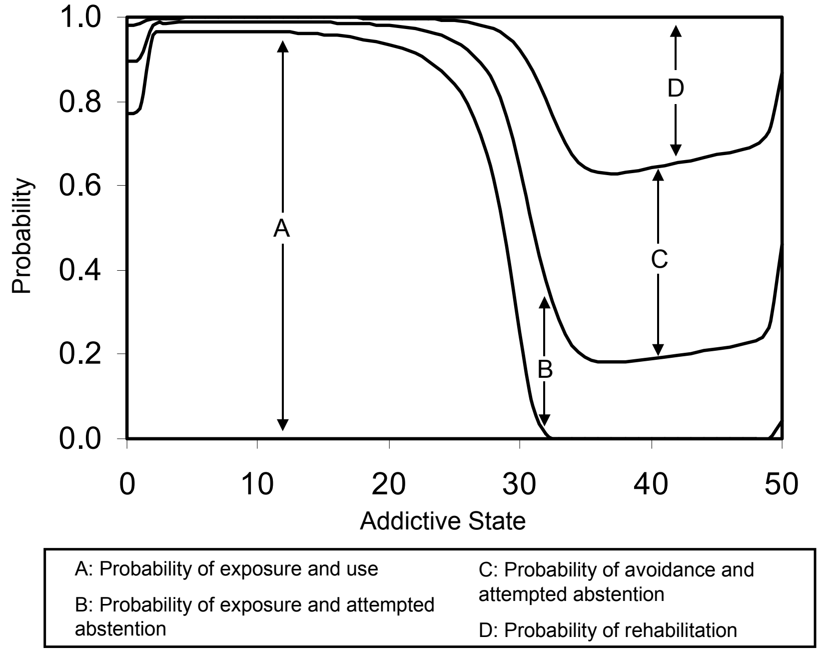

Figure 7: Optimal choices, by addictive state, for a cigarette-like substance

of cue-triggered use) is "fast," while the emergence of costs (declining baseline well being, and deteriorating health) is slow. The latter assumption is appropriate because many of the health problems associated with smoking take decades to develop. In the case considered, the probability of unwanted, cue-triggered use rises to a maximum of 25 percent per week, the net hedonic benefit from smoking is modest (but eventually triples with use), the long-run impact on resources is relatively small ($100 per period), and the long-run effect on baseline well-being (health) is significant. We assume that users incur a cost of $70 per period (based on smoking two packs a day at $5 per pack). Rehabilitation costs $100 per period and involves a relatively modest utility penalty.

Figure 7 shows the probability, by addictive state, of making each of the four possible choices (exposure and use, exposure and attempted abstention, avoidance and attempted abstention, and rehabilitation). Once again, the lowest curve indicates the probability of selecting exposure and use; the difference between the lowest and second-lowest curves indicates the probability of selecting exposure and attempted abstention; the difference between the second-lowest and highest curves indicates the probability of avoidance; and the difference between the highest curve and unity (that is, the top boundary of the graph) indicates the probability of rehabilitation. The graph shows that the individual regularly and intentionally chooses to use the substance at low-

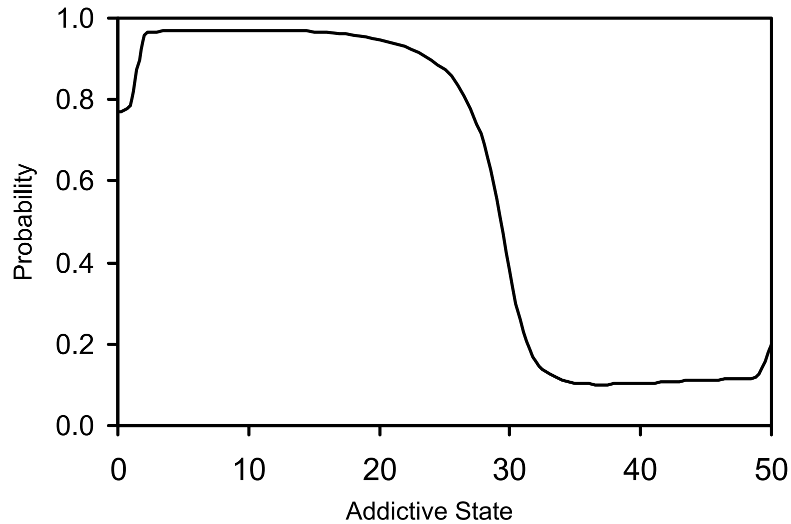

Figure 8: Probability of use, by state, for a cigarette-like substance

to-moderate addictive states. This begins to change around state 25, which, even with constant use, takes nearly 20 years to reach. As adverse health effects begin to develop, the individual tries to abstain. By the time he reaches state 35, there is some intermittent use of rehabilitation. Once again we see some degree of resignation in extremely highly addicted states.

Figure 8 shows the probability of use in each addictive state. At low-to-moderate states, the likelihood of use is extremely high. It declines sharply in moderate-to-highly addictive states as the individual tries to abstain, but remains significantly above zero. This means that use becomes intermittent, as the typical individual bounces back and forth between states with relatively high usage (where he uses intentionally), and those with relatively low usage (where he tries to abstain).

Figure 9 shows the distribution of the population across addictive states in period 1000 (that is, after 20 years). The most individuals achieve moderately highly addictive states over this time frame. They settle into a pattern of alternating between transitory periods of intentional use and attempts to abstain.

Once again, we use our simulation model to calculate aggregate "steady state" elasticities in an economy with a sequence of equally sized overlapping generations. In this case, the price and income elasticities are both close to zero, and probably

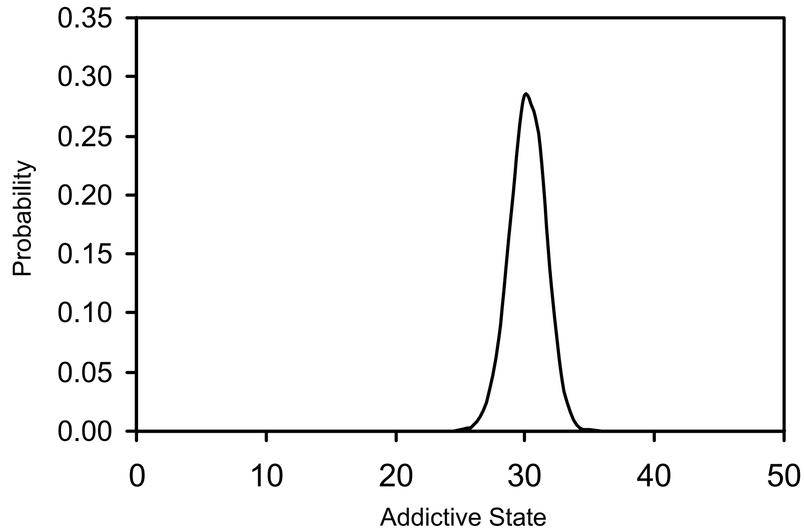

Figure 9: Population distribution, by state, after 20 years, for a cigarette-like substance

unrealistically low. We are in the process of investigating extensions of the model that would inject greater price responsiveness.

5 Standards for Evaluating Public Policies

To evaluate the relative merits of competing public policies, one must necessarily apply criteria for distinguishing good alternatives from bad ones. These criteria may be fuzzy, they may be implicit, and the person performing the evaluation may not be able to articulate them precisely, but they are nevertheless always present whenever one policy is judged superior to another. Economists refer to these as "welfare criteria."

Because of the intellectual history of the discipline has involved a focus on policy evaluation, economics has quite a bit to say about welfare criteria. Economists have made their criteria explicit, quantitative, and precise. This explicit treatment of welfare advances constructive discourse, in that, all too often, parties to policy debates argue over facts, when their real disagreements are over unstated objectives.

The issue of welfare – how to think about what's good and bad in the context of policies toward addictive substances – is central to any discussion of public policies regarding addictive substances. A common objective, often stated in policy debates, is to help drug users. Unfortunately, different people use this phrase to mean different things, which leads them to argue about factual matters at cross-purposes. To some, helping users involves paternalistic interventions; to others, it involves respecting each individual's preferences. By being precise, we can come to understand the sense in which each side has valid points.

5.1 Traditional welfare principles in economics

Traditionally, economists derive their welfare criteria from two guiding principles. We'll refer to these as the *doctrine of individual sovereignty* and the *doctrine of revealed preference*.

The doctrine of individual sovereignty holds that notions of good and bad for society should be rooted in the notions of good and bad held by the affected individuals. In other words, each individual is the best judge of whether one policy leaves him or her better off than another; the government, in particular, does not know better than the individual. This doctrine instructs policy analysts to act as each individual's proxy, by evaluating policies exactly as the individual himself would.

Since this requires the analyst to know the individual's preferences across policies, economists have to rely on the second guiding principle – the doctrine of revealed preference – which states that an individual's choices *always* reveal his or her notions of good and bad. For example, if someone drinks Coke rather than Pepsi, we infer that he likes Coke better than Pepsi. An important branch of economic analysis provides tools for inferring preferences over policy alternatives using data from conventional consumption choices.

As an alternative to revealed preference, one could in principle rely on stated preferences solicited through surveys and/or focus groups. For example, the analyst could ask a sample of the population to rank potential policy changes. Traditionally, economists have been hesitant to use this approach. In many situations, statements about such hypothetical preferences are unreliable. To take an example, while pornography accounts for a large fraction of internet use, few people admit publicly to enjoying it. In contexts where self-reported preferences have been used as a basis for public policy evaluations (e.g., the application of "contingent valuation" to environmental policy), numerous pitfalls have been identified. While it may be possible to elicit useful information about policy preferences through carefully designed protocols, caution is warranted. As a result, economists are generally inclined to believe that actions speak louder than words.

Together, the doctrines of individual sovereignty and revealed preference tell us to respect what people want, and to infer what they want from their choices. An application of these doctrines to addiction leads to the conclusion that the consumption of an addictive substance always reveals a valid preference – a user weighs costs and benefits, and concludes legitimately that the gain is worth the pain.

The first systematic statement of this position in the context of addiction appeared in a seminal paper by Gary Becker and Kevin Murphy, both of the University of Chicago. Their perspective is widely known as the "theory of rational addiction." It holds that addictive substances are distinguished only by the particular pattern of benefits and costs they deliver over time; otherwise, they are just like other goods. This view has been quite influential.

Although this view of addiction strikes most non-economists as obviously incorrect, proponents of Becker and Murphy's paradigm might defend its welfare implications as follows. People do many things that strike outsiders as ill-considered. But that's simply the outsider's judgement, and he or she has no business imposing that judgement on others. To take an example, it's hard to argue that, artistically speaking, Hoobastank is superior to Vivaldi. Yet the fact is that Hoobastank sells more recordings. Even if some of us think that Hoobastank fans might benefit from listening to Vivaldi, most of us acknowledge that this is a matter of taste, and that tastes differ. Given their tastes, some people are happier listening to Hoobastank.

An obvious objection is that comparisons to Hoobastank unfairly trivialize the phenomenon of addiction. After all, addictive substances are highly dangerous; one can't say the same for bad music. But hangliding is dangerous – at one point, there were no living ex-presidents of the American Hangliding Society. Rock climbing, driving a car, and eating fast food are all dangerous. Generally, we don't outlaw activities merely because they're dangerous. Instead, we let each individual decide whether the risks are worth the benefits.

In terms of public policy, the revealed preference perspective implies that there's nothing particularly special about addictive substances. A taste for, say, alcohol, cigarettes, cocaine, or even heroin is seen as simply a reflection of personal preferences, and has the same claim to legitimacy as any other expression of preferences. So, if markets work properly, legalization and laissez faire is best. While we may disagree with drug users' preferences, we have no right to impose our own, any more than we'd have a legitimate interest in forcing Hoobastank fans to listen to Vivaldi.

There are, of course, circumstances in which markets work poorly. In such cases, there may be a compelling justification for government intervention even under the dual doctrines of individual sovereignty and revealed preference. For example, since markets work poorly when people are either uninformed or misinformed, the government can in principle promote consumer welfare through education.

Markets can also perform poorly in the presence of "externalities" – that is, in situations where the actions of one person directly affect another, other than through market transactions. This is relevant to our discussion because the consumption of addictive substances often involves externalities. Driving under the influence leads to accidents, addicts commit crimes to support their habits, and addiction can be devastating to family members. But addictive substances aren't unusual in this respect. Driving a car causes pollution, playing loud music irritates neighbors, using antibiotics helps create resistant strains of bacteria. These are familiar problems, and economists generally believe we should address them by treating the market failure, for example by taxing externality-producing activities. Notably, the policy prescription involves treating the *market*, and not the *individual*. Under this view, there's nothing wrong with the individual.

The critical point is that the traditional revealed preference doesn't recognize the possibility that actions and preferences may systematically diverge – that people make mistakes. And yet, this is fundamentally at odds with the clinical definition of addiction summarized at the outset of Section 2, as well as the evidence from neuroscience discussed in Section 3. This is a critical limitation for public policy analysis since, as we will see, it rules out one of the key rationales for public policy intervention in the context of addiction.

5.2 Alternative welfare principles

There are clearly situations where everyone would agree that actions and preferences diverge – where a choice is obviously not in someone's interest. There are also situations in which most would agree that public policy should recognize these divergences.

Consider the following example. American visitors in London suffer numerous injuries and fatalities because they often look only to the left before stepping into streets, even though they know traffic approaches from the right. Since this is a systematic pattern, one can't dismiss it as an isolated incident. A literal application of the doctrine of revealed preference compels us to conclude either that these people simply prefer to look left, or that they're masochistic. Add the doctrine of individual sovereignty, and there's no legitimate basis for preventing someone from stepping in front of a truck. And yet, it's safe to say that, after recognizing the purpose of the intervention, anyone would be grateful. The pedestrian's objective – to cross the street safely – is clear, and the decision is plainly a mistake.

As another example, consider the treatment of children. Few economists would apply the doctrines of individual sovereignty and revealed preference to evaluate the welfare of a child. We acknowledge that children do not know what's best, and that their actions often fail to reflect valid preferences because they give insufficient weight to consequences. Policies prohibiting the sale of cigarettes and alcohol to minors are therefore relatively uncontroversial. And yet, it's difficult to justify, objectively,

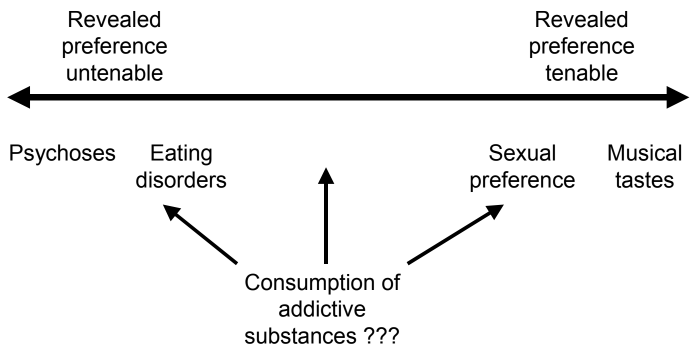

Figure 10: When is revealed preference tenable?

the sense in which the revealed preferences of an irresponsible nineteen-year-old are legitimate, whereas those of a fourteen-year-old are not. While turning eighteen has profound legal significance, it doesn't alter the mechanics of decision-making.

Figure 10 depicts a spectrum of contexts in which some people *might* want to characterize voluntary choices as mistakes. At one end of the spectrum, there are contexts for which the doctrine of revealed preference is clearly tenable, and where there's a compelling case for adhering to it when evaluating public policy. Musical tastes are a case in point. Accordingly, the notion that a Hoobastank fan might be "better off" listening to Vivaldi is not a legitimate justification for, say, taxing Hoobastank CDs, or subsidizing groups that perform Vivaldi's music.

At the opposite end of the spectrum, there are contexts for which revealed preference seems untenable as a guiding principle for public policy evaluation. For example, when people have sufficiently severe diagnosed psychiatric disorders, the state can and should step in to protect them. Eating disorders, while not quite as extreme, provide another illustration. For the purpose of public policy, we probably should *not* proceed on the assumption that an anorexic's refusal to eat is just an expression of valid preferences. On the contrary, we should and generally do regard this as dysfunctional.

Based on the evidence discussed in Section 3, it is appropriate to place addiction with phenomena such as psychoses and eating disorders, rather than with sexual orientation and musical tastes. We emphasize that this classification is based on hard scientific evidence concerning decision processes, rather than subjective normative standards.

Having reached a determination that choices don't reliably reveal preferences in the context of addictive substances, how do we distinguish between good and bad outcomes? This is a thorny issue, and we discuss it at length in Bernheim and Rangel [2005]. One possibility is to interpret the available evidence on addiction through the lens of a structural model of decision making that allows for the possibility of intermittent mistakes, like the one summarized in section 4.1. In practice, economists often use structural models to interpret data and make inferences about consumer well-being, so this is nothing new.

It may, however, be difficult or impossible to reliably estimate a model that allows for mistakes while restricting attention to data on *consumption behavior* (as is traditional among economists). We know of no objective way to determine the incidence of mistakes if we have to allow for the tautological possibility that people always prefer what they choose. Indeed, other scholars have proposed other theories that explain a wide set of addictive behaviors within frameworks that either explicitly invoke, or are at least consistent with, the notion of revealed preference (see e.g. the work on "hyperbolic discounting" by O'Donoghue and Rabin [2000] and Gruber and Koszegi [2001], or the work on "temptation preferences" by Gul and Pesendorfer [2001a,b]).[23]

However, if we supplement behavioral data with other available evidence, it may be possible to reliably estimate a structural model of addiction that allows for intermittent mistakes, and to recover underlying preferences. As one example, we might exploit data on the relationship between intentions and subsequent actions. Knowing the rate of short-term recidivism (say, within one week) among people who decide to quit smoking unconditionally tells us something about the frequency of cue-triggered mistakes, and provides a foundation for making reasonable inferences.

5.3 A Concern

Revealed preference is an attractive *political* principle because it protects individual sovereignty by guarding against abuse. Once we relax this doctrine, we potentially legitimize government condemnation of almost any chosen lifestyle on the grounds that it is contrary to an individual's "true" interests. If we can classify drug use as a mistake, what about choices involving literature, religion, or sexual orientation? If choices don't reveal an individual's notions of good and bad, then "true preferences" become the subject of debate, and every "beneficial" restriction of personal choice

[23]In models with hyperbolic discounting, actions reveal the preferences of multiple selves.

becomes fair game.

The case of sexual orientation is particularly instructive. Until relatively recently, the clinical community classified homosexuality as a psychiatric disorder. Yet this judgement was based primarily on behavioral departures from a perceived norm, rather than on hard, scientific evidence of a decision-process malfunction. The historical treatment of homosexuals in "free" societies illustrates the dangers of legitimizing departures from the doctrine of revealed preference.

Given the clear dangers involved, if we are to relax the principle of revealed preferences in evaluating policies, it behooves us to set a high scientific threshold for reaching a determination, based on objective evidence, that preferences and choices systematically diverge in a given context. Although preliminary progress has been made, this is one of the most important open questions in economics.

6 Policy Implications

In this section, we summarize some of the salient policy implications that follow from our new theory of addiction. We begin by identifying valid policy objectives. We then explain intuitively how specific policies advance or confound these objectives. Finally, we present some numerical simulations to show how the nature of the best available policy depends on the characteristics of the substance.

6.1 Policy objectives

What might society hope to accomplish through public policies regarding addictive substances? Possible objectives include protecting third parties from externalities (e.g. second-hand smoke), combatting misinformation and ignorance, moderating the consequences of uninsurable risks, and helping consumers avoid mistakes. Both externalities and informational problems provide well understood rationales for government intervention, and neither is intrinsically linked to the novel aspects of our framework. We therefore focus here on the last two sets of objectives by studying the impact of public policies when consumers have perfect information about substances and externalities are negligible.

Mistake avoidance. Users and addicts are neither entirely rational, which would argue for minimal interference with consumer sovereignty, nor entirely irrational, which might justify heavy-handed interventions. On the contrary, they are sometimes rational, and sometimes compulsively driven to engage in undesired consumption. In some instances, Draconian policies benefit consumers by preempting mistakes. In other instances, they harm consumers by interfering with free choice. Consumers are generally better served by policies that help them avert mistakes while preserving their discretion to choose.

Moderation of uninsurable risks. Many familiar decisions entail risks. For example, anyone who drives a car runs the risk of an accident. Consumers potentially benefit from pooling risks through insurance. Unfortunately, while the risk of an automobile accident is insurable, others risks are not. One important role of the government is to moderate the consequences of uninsurable risks. This function is known as *social insurance*, and it justifies many prominent public policies, such as unemployment insurance and social security.

The use of addictive substances entails substantial uninsurable risk: fortunate users discover that they can derive pleasure from controlled, intermittent consumption, while unfortunate users become addicted, and find themselves vulnerable to randomly occurring environmental cues, often with dire results. This observation provides a potential economic justification for policies that moderate the negative consequences of addiction. In pressing this agenda, one must of course be cognizant of offsetting costs: moderation of consequences increases incentives for experimentation and use.

6.2 Summary of implications

Potential public policy approaches to addictive substances include criminalization, education, taxation, harm reduction, selective legalization with controlled distribution, restrictions on advertising and market, mandatory provision of counter-cues, and regulation of use. Here we explain, intuitively, how each one advances or confounds specific policy objectives. We refer the reader to Bernheim and Rangel [2004] for a more detailed and mathematically rigorous treatment.

Criminalization. Many societies outlaw the production, distribution, possession and/or use of many addictive drugs, such as cocaine and heroin. This raises the monetary and non-monetary costs of obtaining these substances and makes it more difficult for users to locate supplies, particularly on short notice. As a result, criminalization arguably discourages (and in some instances precludes) consumers from making mistakes.

The new view of addiction raises two additional concerns. First, compulsive use of addictive substances is much less sensitive to costs and consequences than is deliberative use. The effect of criminalization on behavior is therefore potentially smallest when consumption is irrational, and largest when it's rational - precisely opposite the effects of an ideal policy.

Second, criminalization thwarts the social insurance objective by exacerbating the consequences of uninsurable risks associated with the use of addictive substances. When society outlaws a substance, those unfortunate enough to become addicted incur disproportionately high costs. Higher drug prices may lead them to engage in criminal activities such as theft and prostitution, and the consumption of the substance itself brands them as criminals. This is exactly contrary to good social insurance principles.

Education. Successful public education campaigns, such as the U.S. anti-smoking initiative, combat misinformation and ignorance. Education can identify the physiological, psychological, and social consequences of substance abuse. It is not, however, a panacea. Target populations frequently ignore information, particularly when confronted with peer pressure and strong social norms. But more importantly, education cannot alter the neural mechanisms through which addictive substances subvert deliberative decision making. In the context of addiction, one cannot assume that even a highly knowledgeable user always makes informed choices. Consequently, education may be much more effective at discouraging initial experimentation among those who have not yet been neurologically sensitized a substance, than at helping to control abuse among those already addicted.

Tax policy. Society permits the production, distribution, and use of addictive substances such as nicotine and alcohol, but discourages their consumption by imposing high taxes on sales (so-called "sin taxes"). The argument for sin taxes is simple: if the consumption of a good is excessive, discouraging consumption is beneficial. So, for example, Gruber and Koszegi [2001] argue for high sin taxes on the grounds that people place too much weight on immediately gratification (see also O'Donoghue and Rabin [2004]). Since our theory also implies that the consumption of addictive substances is excessive, one might well anticipate a similar prescription. On the contrary, one of the most surprising implications of our theory is that, under plausible conditions, sin taxes are socially harmful.

In principle, by discouraging substance use, taxation does serves the same constructive purposes as criminalization. In fact, in some ways it's better. Criminalization imposes costs on users and producers by dissipating social resources in a manner that is otherwise socially unproductive – like incarceration – whereas taxation collects some of the costs it imposes as revenue. As a general rule, economists therefore tend to prefer taxation to criminalization.

Nevertheless, taxation suffers from some of the same problems as criminalization. Since the imposition of a tax has no effect on the extent to which the substance is readily accessible, it is even less likely than criminalization to discourage problematic compulsive use, relative to rational use. Moreover, like criminalization, taxation exacerbates the consequences of uninsurable risks associated with the use of addictive substance, in the sense that those unfortunate enough to become addicted incur high monetary costs as a result of randomly occurring environmental cues. This is why sin taxation can be socially counterproductive.

Harm reduction policies. Various interventions serve social insurance objectives by ameliorating some of the worst consequences associated with addiction. Some policies reduce risks associated with compulsive choices. For instance, the distribution of clean needles moderates the incidence of diseases among heroin addicts. Since some of these diseases are communicable (e.g., STDs), needle exchanges also help to protect third parties. Other approaches, such as the subsidization of rehabilitation centers and treatment programs (particularly for the indigent), moderate the consequences of becoming addicted by promoting recovery.

Harm reduction policies also have limitations and drawbacks. Though treatment typically emphasizes desensitization to cues, cue-avoidance techniques, and other self-control skills, recidivism rates remain high for most addictive substances. Also, since harm-reducing policies moderate some of the undesirable consequences of substance abuse, they could in principle encourage casual use and experimentation.

Selective legalization with controlled distribution. Some policies permit the sale and/or consumption of addictive substances in certain circumstances but not in others. Examples include a 1998 Swiss law legalizing the prescription of heroin for severely addicted users, and "blue laws" that prohibit the sale of alcohol on Sundays.

This class of policies offers several potential advantages over more extreme approaches such as criminalization and laissez faire. For example, the intent of the Swiss program is to provide addicts with access to the substance at reasonable cost and under safe conditions without legalizing provision to non-addicts. As long as addicts and non-addicts are distinguishable, the policy makes it difficult to engage in undesirable experimentation, while at the same time advancing social insurance objectives by protecting addicts from dire consequences. Addicts with access to inexpensive supplies are also less likely to engage in criminal acts out of desperation.

The new view of addiction places a high value on policies that provide better opportunities for self-regulation, without making particular choices compulsory. It is important to remember that use is sometimes rational and sometimes irrational, and that it's very difficult to ascertain which condition prevails in any given instance. By improving opportunities for self-management, we help those who are victims of compulsive use, without encroaching on the freedoms of those who would deliberately choose to use.

Regulation could in principle accomplish this objective more effectively. For example, if prescription orders for a substance are filled on a "next day" basis, then deliberate forward-looking planning becomes a prerequisite for availability. Recovering heroin addicts could self-regulate problematic compulsive use by carefully choosing when, and when not, to file requests for refills.

Cognitive policies. Since environmental cues frequently trigger addictive behaviors, public policy can also influence use by changing the cues that people normally encounter. One approach involves the elimination of certain problematic cues. One effect of advertising and marketing restrictions of the type imposed on sellers of tobacco and alcohol is to eliminate an artificial cause of compulsive use.

A second approach involves the creation of counter-cues. Brazil and Canada require every pack of cigarettes to display a prominent, viscerally charged image depicting some deleterious consequences of smoking, such as lung disease and neonatal morbidity. In principle, a sufficiently strong counter-cue could trigger thought processes that induce users to resist cravings, even though the same information is ineffective when offered in a less provocative format.

Policies that eliminate problematic cues or promote counter-cues are potentially beneficial because they combat compulsive use while imposing a minimal inconvenience and restrictions on deliberate rational users.

Regulation of use. Even when the consumption of a substance is legal, use is sometimes regulated. Driving under the influence is universally outlawed, and public smoking is limited to specially designated areas in certain U.S. cities. These policies are primarily motivated by the desire to protect third parties from drunk drivers and second-hand smoke, but they may provide additional benefits. For example, some smokers have greater difficulty resisting cravings when they encounter others in the act of smoking. In such instances, confining use to designated areas removes an environmental cue capable of triggering compulsive use.

It is important to emphasize that no single combination of policies is ideal for all addictive substances. For example, while alcohol and crack cocaine are both addictive, public policy should (and does) treat them differently. A number of factors affect the relative desirability of the various alternatives, including (but not limited to) the typical individual's susceptibility to addiction, the relative frequencies of deliberate and compulsive consumption among users, the responsiveness of compulsive and deliberate use to prices and other incentives, and the magnitude of costs imposed on third parties. It is also important to stress that the ideal policy regime for any particular substance may evolve over time as our ability to treat, control, and/or predict addiction develops.

6.3 Simulation results

Next we present some simulation results. Our purpose is both to illustrate some of the policy implications discussed in the previous section, and to provide a rough indication of the policy magnitudes. We consider the two cases discussed in Section 4.2 – a heroin-like substance, and a cigarette-like substance. Our results for these cases are preliminary. We have not yet carefully calibrated the simulation model to all of the available data and information. Nor have we yet extended the model to encompass all potentially salient considerations. Consequently, at this stage of our research, our results are merely suggestive, and are not intended as policy recommendations. Producing more refined and reliable simulation results of potential use in practical policy analysis is an important objective of our ongoing research agenda.

We simulate the effects of taxes and subsidies (a subsidy simply being a negative tax), both on the substance and on rehabilitation, balancing the government's budget through lump sum levies and distributions, and determine the extent to which these harm or hurt consumers. It is important to emphasize that subsidization does not necessarily benefit consumers, since they have to pay for subsidies through other (lump sum) taxes. Indeed, with non-addictive goods, and in the absence of externalities, both taxes and subsidies would be harmful – the best solution would be laissez faire.

We find that small subsidies (one dollar per unit) for the two addictive substances considered here are beneficial, while small taxes (also one dollar per unit) are harmful. For example, in monetary terms, the net benefit of a small subsidy for the heroin-like substance is equal to 7.1 percent of the required revenue, so consumers come out ahead by just over seven cents on each dollar they give up.

Next we focus on optimal tax/subsidy rates for the addictive substances. In both cases, the best policy involves a subsidy. For the heroin-like substance, the optimal subsidy is $22 per unit (where a unit is defined as the amount consumed in a week), or 11 percent of price. In monetary terms, the net benefits of the subsidy are 3.3 percent of the required revenue. For the cigarette-like substance, the optimal subsidy is $12 per unit, or 17 percent of price.

As a caveat, we emphasize that, once externalities are taken into account, taxation, rather than subsidization, may be optimal. However, our provisional conclusion is that considerations of "harm-to-self" (sometimes called "internalities") at a minimum reduce the appropriate level of taxation. This is in sharp contrast to work based on the other leading model of self-control problems, which suggests that sin taxes should be considerably higher when harm-to-self is considered (Gruber and Koszegi [2001]).

Next we focus on optimal tax/subsidy rates for rehabilitation. In both cases, the best policy again involves a subsidy. For the heroin-like substance, the optimal subsidy is $31 per incident, or 12 percent of the cost. For the cigarette-like substance, it is $35, or 35 percent of cost. Consideration of externalities would probably justify even higher subsidies.

The results presented so far are based on optimizing the tax rates – either for the substance or for rehabilitation – one at a time, while setting the other to zero. We have also optimized over both policy instruments simultaneously. For the heroin-like substance, we find that the optimal subsidies are $22, or 11 percent, for the substance, and $28, or 11 percent, for rehabilitation. In other words, neither subsidy has much of an effect on the other's optimal level. In contrast, the answers change considerably for the cigarette-like substance: the optimal subsidies are $64, or 91 percent, for the substance, and $12, or 12 percent, for rehabilitation. We have not yet determined why these policies instruments would interact significantly in one instance, but not in the other.

7 Conclusions

Governments should choose policies that promote the well-being of their citizens. Moreover, notions of good and bad for society should be rooted in the notions of good and bad held by the affected individuals. In most instances, it is appropriate to infer the preferences of the affected individuals from their actions. However, in the context of addiction substances, objective scientific evidence overturns the validity of this principle. Specifically, recent research in neuroscience supports the view that the consumption of addictive substances is sometimes rational, and sometimes a cue-triggered mistake. Neuroscientists have gained considerable insight into the specific processes that appear responsible for decision-making malfunctions involving addictive substances, and into the conditions under which these malfunctions occur. These insights lead to a new behavioral theory of addiction that bridges the gap between neuroscience and public policy. While the theory identifies a potential role for Draconian policies such as criminalization, it explicitly cautions against strategies that tend to magnify economic burdens on those who become addicted, and underscores the benefits of policies that reduce these burdens. For example, it suggests that, even when addictive substances are consumed to excess, "sin taxes" are counterproductive in identifiable circumstances. It also places a high value on policies that increase the likelihood of successful self-regulation without making particular choices compulsory, and it identifies a central role for "cognitive" policies, including the suppression of certain environmental cues (e.g., through limitation on advertising), and the dissemination of counter-cues.

References

[1] Behara, A. and H. Damasio (2002a) "Decision-making and addiction. Part I. Impaired Activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences," Neuropsychologia, 40:1675-89.

[2] Bechara, A. and H. Damasio (2002b) "Decision-making and addiction. Part II. Myopia to the Future or Hypersensitivity to Reward?," Neuropsychologia, 40:1690-705.

[3] Bechara, A. and A. Damasion (2005) "The somatic marker hypothesis: a neural theory of economic decision," Games and Economic Behavior, 52(2):336-372.

[4] Becker, Gary and Kevin Murphy (1988) "A Theory of Rational Addiction," Journal of Political Economy, 96(4), 675-700.

[5] Bernheim, B. Douglas and Antonio Rangel (2004) "Addiction and Cue-Triggered Decision Processes," American Economic Review 94(5): 1558-1590.

[6] Bernheim, B. Douglas and Antonio Rangel (2005) "Behavioral Public Economics: Toward Welfare Analysis with Fallible Consumers," forthcoming in *Economic Institutions and Behavioral Economics*, Peter Diamond and Hannu Vartiainen (eds.), Princeton University Press.

[7] Berridge, K. (1996) "Food Reward: Brain Substrates of Wanting and Liking," Neuroscience and Biobehavioral Reviews, 20(1):1-25

[8] Berridge, K. (1999) "Pleasure, Pain, Desire, and Dread: Hidden Core Processes of Emotion," in *Well-Being: The Foundations of Hedonic Psychology*, D. Kaheman, E. Diener, and N. Schwarz (eds.), 525-57

[9] Berridge, Kent, and Terry Robinson (1998) "What is the role of dopamine in reward: hedonic impact, reward learning, or incentive salience?", Brain Research Review, 28:309-69.

[10] Berridge, Kent and Terry Robinson (2003) "Parsing Reward," TRENDS in Neurosciences, 26(9):507-513.

[11] Bolla, JI, JL Cadet, and ED London (1998) "The neuropsychiatry of chronic cocaine abuse," Journal of Neuropsychiatry and Clinical Neuroscience, 10:280-89.

[12] Brauer, LH et. al. (1997) "Dopamine ligands and the stimulus effects of amphetamine: animal models versus human laboratory data," Psychopharmacology, 130:2-13.

[13] Brauer, LH et. al. (2001) "Haloperidol reduces smoking of both nicotine-containing and denicotenized cigarettes," Psychopharmacology, 159:31-37.

[14] Center for Disease Control (1993), "Smoking-Attributable Mortality and Years of Potential Life Lost - United States, 1990," *Morbidity and Mortality Weekly Report*, 42(33), 645-8.

[15] Chaloupka, F. and K. Warner (2001) "The Economics of Smoking", in J. Newhouse and D. Cutler (eds.), *Handbook of Health Economics,* North-Holland.

[16] Cohen JD and KI Blum (2002) "Reward and Decision," Neuron, 36:193-98.

[17] Di Chiara, G. (1999) "Drug addiction as dopamine-dependent associate learning disorder," European Journal of Pharmacology, 375:13-30

[18] Gardner, Eliot and James David (1999) "The Neurobiology of Chemical Addiction," in *Getting Hooked: Rationality and Addiction*, edited by Jon Elster and Ole-Jorgen Skog. Cambridge: Cambridge University Press.

[19] Goldstein, A. (2001) *Addiction: From Biology to Drug Policy.* Second Edition. New York: Oxford University Press.

[20] Goldstein, A. and H. Kalant (1990) "Drug Policy: Striking the Right Balance," Science 249: 1513-21.

[21] Gruber, Jonathan, and Botond Koszegi (2001) "Is Addiction "Rational"? Theory and Evidence," Quarterly Journal of Economics, 116(4): 1261-1303 .

[22] Gul, Faruk and Wolfgang Pesendorfer (2001a), "Temptation and Self-Control", Econometrica 69(6): 1403-35.

[23] Gul, Faruk and Wolfgang Pesendorfer (2001b) "A Theory of Addiction," Princeton mimeo.

[24] Harris, J.E. (1993) *Deadly Choices: Coping with Health Risks in Everyday Life.* New York: Basic Books.

[25] Holden, C. (2001a) "'Behavioral' addictions: Do they exist?" Science, 294:980-82.

[26] Holden, C. (2001b) "Zapping Memory Centers Triggers Drug Craving," Science, 292:1039

[27] Hser, Y.I., D. Anglin, and K. Powers (1993) "A 24-year follow-up study of California narcotics addicts," Archives of General Psychiatry, 50:577-84.

[28] Hser, Y.I., V. Hoffman, C. Grella, and M.D. Anglin (2001) "A 33 year follow-up of narcotics addicts," Archives of General Psychiatry, 58:503-8.

[29] Hung, Angela (2000) “A Behavioral Theory of Addiction,” Caltech, manuscript.

[30] Hyman, Steven and Robert Malenka [2001] “Addiction and the Brain: The Neurobiology of Compulsion and Its Persistence,” Nature Reviews: Neuroscience, 2: 695-703.

[31] Jentsch, JD and JR Taylor (1999) “Impulsivity Resulting from frontostriatal dysfunction in drug abuse: implications for the control of behavior by reward-related stimuli,” Psychopharmacology, 146:373-90.

[32] Kelley, A.E. (1999) “Neural integrative activities of nucleus accumbens subregions in relation to learning and motivation,” Psychobiology, 27:198-213.

[33] Kaczmarek, HJ and Kiefer SW (2000) “Microinjections of dopaminergic agents in the nucleus accumbens affect ethanol consumption but not palatability,” Pharmacology, Biochemistry, and Behavior, 66:307-12.

[34] Krawczykw, DC (2002) “Contributions of the Prefrontal cortex to the neural basis of human decision making,” Neuroscience Biobehavioral Reviews, 26:631-64.

[35] Loewenstein, George (1996) “Out of Control: Visceral Influences on Behavior,” Organizational Behavior and Human Decision Processes, 65(3) 272-92.

[36] Loewenstein, George (1999) “A Visceral Account of Addiction,” in Jon Elster and Ole-Jorgen Skog (eds.) *Rationality and Addiction*. Cambridge: Cambridge University Press.

[37] MacCoun, R. and P. Reuter (2001) *Drug War Heresies: Learning from Other Vices, Times, and Places.* Cambridge University Press.

[38] National Institute on Alcohol Abuse and Alcoholism (2001), “Economic Perspectives in Alcoholism Research”, *Alcohol Alert*, National Institutes of Health, No. 51.

[39] National Institute on Drug Abuse (1998). *The Economic Costs of Alcohol and Drug Abuse in the United States, 1992.* Bethesda, MD: National Institutes of Health (NIH Publication Number 98-4327).

[40] Nestler, E.J. (2001) “Molecular Basis of Long-term Plasticity Underlying Addiction”, Nature Reviews Neuroscience, 2:119-28.

[41] Nestler, E. and Robert Malenka (2004) “The Addicted Brain,” Scientific American, March:78-85.

[42] Norstrom, T., and O.J. Skog (2003) “Saturday opening of alcohol retail shops in Sweden: an impact analysis,” J Stud Alcohol, 64(3):393-401.

[43] O'Brien, C. (1976) "Experimental analysis of conditioning factors in human narcotic addiction," Pharmacological Review, 25:533-43.

[44] O'Brien, C. (1997) "A Range of Research-Based Pharmacotherapies for Addiction," Science, 278:66-70.

[45] O'Donoghue, Ted, and Matthew Rabin (2000), "Addiction and Present-Biased Preferences," manuscript, UC Berkeley.

[46] O'Donoghue, Ted, and Matthew Rabin (2004), "Optimal Sin Taxes," manuscript, UC Berkeley.

[47] Office of National Drug Control Policy (2001a). *What American Users Spend on Illegal Drugs.* Washington, DC: Executive Office of the President (Publication No. NCJ-192334).

[48] Office of National Drug Control Policy (2001b). *The Economic Costs of Drug Abuse in the United States, 1992-1998.* Washington, DC: Executive Office of the President (Publication No. NCJ-190636).

[49] Olds, J. and P. Milner (1954) "Positive reinforcement produced by electrical stimulation of septal area and other regions of rat brain," Journal of Comparative and Physiological Psychology, 419-27.

[50] Pecina, S., et. al. (1997) "Pimozide does not shift palatability: separation of anhedonia from sensorimotor suppression by taste reactivity," Pharmacological Biobehavioral Reviews, 58:801-811.

[51] Pickens, R. and W.C. Harris (1968) "Self-administration of d-amphetamine by rats," Pscyhopharmacologia, 158-63.

[52] Redish, David (2004) "Addiction as a computational process gone awry," Science, 306:1994-47

[53] Robbins, T.W. and Everitt B.J. (1999) "Interaction of depaminergic system with mechanisms of associative learning and cognition: implications for drug abuse," Psychological Science, 10:199-202.

[54] Robins, L. (1994) "Vietnam Veterans' Rapid Recovery from Heroin Addiction: a Fluke or Normal Expectation," Addiction, 1041-54.

[55] Robins, L., D. Davis, and D. Goodwin (1974) "Drug Use by U.S. Army Enlisted Men in Vietnam: a Follow-up on their Return Home," American Journal of Epidemiology, 235-49.

[56] Robinson. T. and K. Berridge (1993) "The Neural Basis of Drug Craving: An Incentive-Sensitization Theory of Addiction," Brain Research Reviews, 18(3):247-91.

[57] Robinson, T. and K. Berridge (2000) "The psychology and neurobiology of addiction: an incentive sensitization view," Addiction, Suppl 2:91-117.

[58] Robinson, Terry and Kent Berridge (2003) "Addiction," Annual Reviews of Psychology, 54:25-53.

[59] Rolls, E.T. (2000) "The orbitofrontal cortex and reward," Cerebral Cortex, 10:284-94.

[60] Schultz, W. (1998) "Predictive reward signal of dopamine neurons," Journal of Neurophysiology, 80:1-27.

[61] Schultz, Wolfram (2000) "Multiple Reward Signals in the Brain,"Nature Reviews Neuroscience, 1:199-207.

[62] Schultz, W., P. Dayan, and P.R. Montague (1997) "A neural substrate of prediction and reward," 275:1593-99.

[63] Trosclair, A., C. Huston, L. Pederson, and I. Dillon (2002), "Cigarette Smoking Among Adults – United States, 2000," *Morbidity and Mortality Weekly Report*, 51(29), 642-645.

[64] United States Census Bureau (2001). *Statistical Abstract of the United States.* Washington, DC: US Government Printing Office.

[65] Vorel, S. and E. Garner (2001) "Drug Addiction and the Hippocampus," Science, 294(9):1235a

[66] Vorel, S., et. al. (2001) "Relapse to Cocaine-Seeking After Hippocampal Theta Burst Stimulation," Science, 292:1175-78.

[67] Wachtell, SR (2002) "The effects of acute haloperidol or risperidone on subjective responses to methamphetamine by healthy volunteers," Drug Alcohol Dependency, 68:23-33.

[68] Wagner, F.A. and J.C. Anthony (2002) "From first drug use to drug dependence: developmental periods of risk for dependence upon marijuana, cocaine, and alcohol," Neuropsychopharmacology, 26:479-88.

[69] Wickelgren, I. (1997) "Getting the Brain's Attention," Science, 278:35-37.

[70] Wise, Roy (1989) “The Brain and Reward,” in The Neuropharmacological Basis of Reward, ed. JM Liebman, SJ Cooper, New York, Oxford University Press, pp. 377-424

[71] Wyvell, CL and KC Berridge (2000) “Intra-accumbens amphetamine increases the conditioned incentive salience of sucrose reward: enhancement of reward wanting without enhancing liking or positive reinforcement,” Journal of Neuroscience, 20:8122-30.