Multiple Addictions

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Abstract

A simple extension of the rational addictions model does away with the two main criticisms brought against this model in the literature. Simply allowing for more than one addictive good or habit in the utility function allows the model, first, to generate any type of cyclical patterns in consumption (damped, explosive, or persistent) under no special conditions and, second, to generate both abrupt and smooth decisions to cessate strong addictions. Thus, this innocuous extension of the model is able to explain the observed relapses, binges, and episodic consumption of addictive goods. Empirically, multiple habits and addictions would seem to be the rule rather than the exception. Yet, theoretically and empirically each addiction has been treated individually in most of the literature. Multiple habits and addictions also have fundamental implications for drug policy analysis, the theory of consumption with habit persistence, and the econometric specification of empirical models of addiction.

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1 Introduction

The problems, social causes, and policy implications of addiction have attracted much attention from psychiatrists, neurobiologists, sociologists, and economists in recent years. A critical question in these literatures, with significant ramifications for health and social policy, is the rationality of addiction. Becker and Murphy (1988) develop a model of rational addiction where individuals maximize stable preferences over time. Their model includes the following three essential characteristics of addiction: (i) Withdrawal: cessation of consumption causes disutility; (ii) Reinforcement: past consumption of an addictive good raises the marginal utility of current consumption, a characteristic that has the important implication that the consumptions of an addictive good at different times are complements; (iii) Tolerance: the stock of past consumption affects current utility; if it increases current utility then the addiction is termed beneficial whereas if it causes disutility it is considered harmful.[1]

The empirical predictions of the model of rational addiction have been tested and confirmed with evidence from the demand for several goods, including cigarettes, alcoholic beverages, cocaine, gambling, caffeine, and calories.[2] In particular, the evidence shows that long-run price elasticities are sizable and much bigger than short-run elasticities, higher past as well as future prices reduce current consumption, younger persons respond more to changes in prices of addictive goods than do older persons, higher-income persons respond more to changes in future harmful effects and less to changes in prices of addictive goods than do lower income persons, and fluctuations in the stock of consumption increase with age.

This empirical support is in sharp contrast with a great deal of skepticism and criticism that has been brought against the model in the literature. Critics, moreover, often suggest abandoning the rational model altogether and offer, as an alternative,

[1]There are other models of rational addiction as well. Orphanides and Zervos (1995) propose a model that includes uncertainty and learning about the effects of the addictive good. Laibson (2001) embeds environmental cues in a variant of the Becker-Murphy model where consumers have dynamically consistent preferences.

[2]Becker, Grossman and Murphy (1994), Cawley (1999), Chaloupka (1996), Chaloupka et al. (1999), Grossman et al. (1998), Olekalns and Bardsley (1996), and other references therein collect much of this evidence and offer throrough reviews of the empirical literature on rational addiction.

models that include various forms of irrationality such as weak wills, self-control problems, myopic behavior, and visceral impulses.[3]

First, the rational approach has been criticized as unrealistic. It is considered that it includes "rather strong assumptions about human actions, ..., assumptions that may not be entirely realistic" (Skog, 1999, pp. 188-201), and that "the most obvious reason to study self-control [and other irrational] models is simple realism" (O'Donoghue and Rabin, 1999, p. 198). A theory, however, cannot be tested by the realism of its assumptions. Friedman (1953, p.14) dismisses this criticism of economic models by arguing how "to suppose that the conformity of the 'assumptions' to 'reality' is a test of the validity of the hypothesis *different from* or *additional to* the test by its implications ... is fundamentally wrong and productive of much mischief" (italics and quotations are his).[4]

A second type of objections to the rational model are much more compelling. They are concerned with two classes of empirical regularities that are difficult to explain within this framework. The first class of empirical regularities are concerned with the decision to relapse and with the different cyclical patterns of consumption that are observed for different addictive goods. It is considered that the rational choice model is "especially hard pressed to explain why people relapse after having stayed off for a considerable period of time" (Skog, 1999, p.192). The reason is that often addiction does not entail continuous or even highly regular consumption of a drug. Consumption of many drugs is episodic, and many, if not most, addicts go through periods of abstinence, which are typically interrupted by relapse. For example, for some alcoholics periodic binges (cycles over time in consumption) are followed by long periods of little or no drinking. Cigarette smokers are notorious for their frequent, but often unsuccessful attempts to quit permanently. Even cocaine addicts alternate between binges and abstinence (Gawin, 1991). The lengths of periods of use and

[3]See, for instance, Ainslie (1992), Herrnstein and Prelec (1992), Gruber and Köszegi (2001), O'Donoghue and Rabin (1999), and Loewenstein (1996, 1999) for recent nonrational and myopic models of addiction, and Elster (1999a, 1999b) for two edited volumes that collect further work in this area. Gul and Pesendorfer (2001) consider the problem of addiction in the context of a model of temptation. Bernheim and Rangel (2002) study a neurobiological model of addiction.

[4]As Orphanides and Zervos (1995) note, these criticisms already started as a criticism of Stigler and Becker (1977). Friedman (1953, p.15) defends that "the relevant question to ask about the assumptions of a theory is not whether they are descriptively 'realistic,' for they never are, but whether they are sufficiently good approximations for the purpose in hand. And this question can be answered only by seeing whether the theory works, which means whether it yields sufficiently accurate predictions."

abstinence, and the cyclical patterns of consumption are indeed quite variable and different across the different addictive goods (Tims et al., 2001). It is argued in the literature that rational theories of addiction have a difficult time dealing with such episodes (e.g., Loewenstein, 1999).

It is not impossible for the rational model to generate binges, but it certainly is difficult. The difficulties arise from the very special conditions under which binges and relapses occur. In the Becker-Murphy model of addiction, binging may be made consistent with rationality by assuming that *two* stocks of a single consumption good determine current consumption.[5] The model may then generate binges if the two stocks have different depreciation rates and different degrees of complementarity and substitutability with consumption in a specific way. In the example they discuss, to get cycles of overeating and dieting, one stock (eating capital) must be complementary with eating and have the higher depreciation rate, while the other stock (weight) must be substitutable and have the lower depreciation rate. In general, the stock with the higher depreciation rate must have adjacent complementarity while the other stock must have adjacent substitution. These special conditions, however, are considered to be too stringent. The reason is that relapses, binges, and episodic consumption are observed for virtually all addictive goods, both harmful and beneficial. While for some of them two stocks can be intuitively identified and can be given a plausible interpretation, it may be difficult, perhaps even impossible, to always find two stocks for *all* addictive goods where binges are observed. Moreover, it also seems unlikely that even if two stocks are identified, they turn out to have the required properties in terms of differences in rates of depreciation and degrees of adjacent complementarity and substitutability in each and every case.

The second class of empirical regularities that are brought against the model are concerned with the decision to cessate consumption. The theory of rational addiction allows for abrupt cessation of consumption ("cold turkey"), but it also *requires* strong addictions to terminate with cold turkey. While some medical and clinical drug experts claim that cold turkey may often be the best solution to addiction, empirical evidence suggests that this is not the typical way strong addictions cessate. For instance, in a four-year follow-up of treated alcoholics Skog and Ducket (1993) find

[5] See also Dockner and Feichtinger (1993). There is no possibility of relapse in Orphanides and Zervos' (1995) model and no recovery possible for any addicts who fall into the addictive steady state.

that only a small fraction of them were consistently abstaining, while a substantial proportion were drinking within moderate limits, and some were drinking excessively. Hubbard et al. (2001) find that most cocaine and heroin users shift to less heavy use patterns of the same drugs after treatment, or substitute them for other narcotics. Tims et al. (2001) collect various studies with similar findings for other drugs.

These two classes of empirical criticisms are important. The empirical regularities concerning cycles in consumption, as well as the decisions to relapse and the observed forms of cessation, are important phenomena that should be explained by *any* successful theory of addiction. In this paper, we show how a rather simple and natural extension of the rational addiction model allows the model to explain these empirical phenomena. In particular, the analysis brings attention to the role of multiple goods and activities with addictive or habitual characteristics. Once multiple goods are incorporated, it is not necessary to find two stocks for each and every addictive good under consideration, nor is it necessary to require any special conditions with regard to their depreciation rates and their degrees of complementarity and substitutability with other goods. The observed cycling patterns of consumption and the observed patterns of relapse and cessation can then be explained without requiring any stringent conditions.

The motivation for considering multiple addictions and habits is rather natural. Several goods and activities would seem to have the characteristics of habits and addictions mentioned earlier. People get addicted not only to alcohol, eating, cocaine, coffee, and cigarettes but also to work, music, television, exercising, their standard of living, internet, other people, leisure, religion, and many other goods and activities. These and other examples include both negative as well as positive habits and addictions.[6] In his extensive survey, Peele (1985) considers that addiction may occur with any potential experience. He concludes that if somebody derives a great deal of satisfaction, say, from haute cuisine, soccer, listening to classic music, collecting stamps or watching birds, that activity is potentially addictive. It seems apparent that a variety of goods and activities, both harmful and beneficial, may have the properties of addictive goods outlined earlier, and that many of them may be related with others in various ways. Yet, each addiction has virtually always been treated individually in theoretical and empirical work. As indicated above, simply allowing for

[6] Among the different models considered in the economics literature, only the model by Becker and Murphy (1988) has room for the idea of positive addictions.

multiple addictions or habits to coexist in the instantaneous utility function will be sufficient to explain the important empirical regularities that are difficult to explain within the current rational framework with a single good.

Casual evidence already suggests plausible relationships between different habits and addictions. For instance, television and obesity, work and coffee, marijuana and alcohol, reading and classical music, and other may perhaps be related in various ways in certain instances. More importantly, within the context of harmful addictions, an extensive clinical literature in medicine and psychiatry explicitly emphasizes the importance of multiple addictive goods for understanding the varying patterns of consumption, relapse, and cessation for harmful addictions, that is for understanding the empirical regularities described above.[7] Tims et al. (2001) collect a number of studies on relapse and recovery in addictions which describe in detail the different addiction patterns and patterns of cessation observed for several different drugs. These studies stress that in order to understand relapse to drug abuse it is crucial to focus on the multidimensional nature of drug consumption. For instance, the basic definition of "relapse in terms of use of a *single* substance such as heroin, alcohol, or tobacco ... fails to capture the nature of drug abuse and may lead to misguided policy and practice guidelines. The understanding of relapse to drug abuse is complicated by current drug abuse patterns that involve *multiple* use of a wide range of types of licit and illicit drugs" (Hubbard et al., 2001, p.110). Multiple drug use is indeed considered to be a persistent and increasingly prevalent feature of addiction in the medical literature. A common pattern among subjects entering treatment in major clinical studies in the 1970s through the 1990s is the weekly or more frequent use of several drugs including marijuana, cocaine, alcohol, and heroin (Hubbard et al., 1985).[8] The types and patterns of complementarities and substitutabilities among addictive goods in consumption, cessation, and relapse are very different. For instance, heroin abusers typically use marijuana, cocaine, and alcohol and many, after treat-

[7]The medical literature refers to the repeated cycles of cessation and relapse that are observed in the consumption of drugs over extended periods as a "drug use career," "dependence career," or "addiction career." These careers can vary widely across different goods in terms of length, patterns (frequency, severity, latency, multiplicity of drug consumption, and duration of periods of use and abstinence), and ultimate outcomes among drug users.

[8]See, for instance, the different studies collected in Tims et al. (2001) which describe the Drug Abuse Reporting Program (DARP) in the 1970s, the Treatment Outcome Prospective Study (TOPS) in 1979-1981, and the Drug Abuse Treatment Outcome Studies (DATOS) in 1991-1993, on about 10,000, 8,000, and 12,000 subjects respectively.

ment, substitute these drugs for heroin. About three quarters of cocaine abusers are also diagnosed with alcohol abuse or dependence (see Rohsenow and Monti (2001)). Cocaine is commonly used with alcohol and marijuana but infrequently with other non-opioid drugs. The problem of multiple drug use is so apparent and important that drug abuse studies and treatment programs classify the different patterns of multiple drug use before, during, and after treatment using a classification system that includes different combinations of weekly use of up to eight drug types. Yet, formal and empirical models in economics largely consider addictions individually.[9]

We conclude the examples that motivate our analysis with perhaps one of the most natural and in some sense important ones, namely the relationship between the demands for cigarettes and calories. This relationship is important because these two goods are conductive to the two leading causes of preventable death in the United States and other developed countries: smoking and obesity. Evidence indicates that tobacco smoking reduces appetite, and that smoking cessation leads to weight gain. The neurobiology of this relationship is well known in medicine.[10] Froom et al. (1998) review the extensive medical literature on the relationship between smoking and weight. Most studies find that smoking behavior is related to a belief and an awareness that smoking controls weight, and that weight consciousness and *anticipation* of weight gain predicts current smoking, as well as attempts to quit smoking and *recidivism* after smoking cessation. Again, despite the extensive evidence on the relationship between smoking and eating, empirical studies in economics on these two addictions have always treated them individually, separately from each other.

In this paper, we show that the important empirical objections concerning the rational model can be readily dismissed by simply allowing more than one addictive good to enter in the instantaneous utility function. Once multiple addictive goods are incorporated into the framework, different types of cycles in consumption (damped, explosive, or persistent), different patterns of relapse in the consumption of addictive goods, and abrupt as well as smooth cessation patterns can be explained without requiring any stringent or special conditions.

[9]See, for instance, Chaloupka et al. (1999a,b), Pacula (1997, 1998) for some exceptions. Others are discussed in section 3.

[10]Nicotine affects appetite regulation, in part by changes in serotonin and dopamine in the lateral hypothalamic area (Miyata et al. (1999)). Niklas et al.'s (1999) findings indicate that cigarette smoking directly elevates the concentrations of plasma leptins, an endocrine signal that regulates body fat stores through hypothalamic control of energy intake.

The analysis is also relevant in another dimension. Economists and policy makers are beginning to consider the effects of policies targeting *one* substance on the use of *other* substances in the area of substance control policy. However, the economic and econometric frameworks of research exploring the relationship between the demands for different drugs that are needed to inform these discussions are sorely lacking, as multiple addictive goods have not been considered in either rational or irrational models of addiction. Yet, it seems apparent that developing policies that will lead to sustained long-run reductions in drug use requires consideration of all intended and unintended effects. A drug policy that successfully discourages smoking at the expense of obesity or that discourages heavy drinking at the expense of increased abuse of cocaine would presumably be less desirable than one that does not have such effects. As a more general proposition, it is not sufficient to consider the consumption of different addictive goods independently. Models that include multiple addictive goods may offer valuable guidance that will help evaluate the full impact of public interventions, including the optimal level of taxation, the effects of different forms of regulation, and the impacts of legalization.

2 A Rational Multiple Addictions Model

We first develop in this section a tractable framework that examines the relationship between the demands for different addictive or habitual goods in the rational addictions model. We then report a number of numerical examples that show how any type of consumption cycles and any patterns of relapse and cessation may be obtained under general conditions.

2.1 Theoretical Framework

The basic Becker-Murphy model of addiction considers one addictive good and one non-addictive good. This allows the model to deliver in a transparent way a variety of predictions that have found substantial empirical support in recent research. The model is extended next to include various addictive goods. For simplicity, we consider just two addictive goods, rather than one addictive, along with one non-addictive good. This is sufficient to enrich the model in a fundamental way and deliver as transparently as possible the qualitative nature of the results.

Consider a rational individual who at each instant derives utility from consumption of three goods c_1, c_2 and y. These goods are distinguished by assuming that the instantaneous utility function also depends on past consumptions of c_1 and c_2, but not of y:

$$u(t) = u\left[c_1(t), c_2(t), y(t), S_1(t), S_2(t)\right].$$

Past consumptions of c_1 and c_2 affect current utility through the accumulation processes:

$$\begin{aligned}\overset{\bullet}{S}_1(t) &= c_1(t) - \delta_1 S_1(t),\\ \overset{\bullet}{S}_2(t) &= c_2(t) - \delta_2 S_2(t),\end{aligned}$$

where $\overset{\bullet}{S}_i(t)$ is the rate of change over time in the stock of consumption capital $S_i(t)$ and δ_i is the instantaneous depreciation rate. Each consumption good accumulates a single stock, so the stocks of consumption are commodity specific. The individual is assumed to engage in no endogenous depreciation or appreciation of the addictive stocks. We assume that utility is a strongly concave function of c_1, c_2, y, S_1 and S_2. Clearly, this formulation continues to consider the three essential characteristics of addiction, namely withdrawal, reinforcement, and tolerance.

Consider an infinitely-lived individual with a constant rate of time preference, σ, who maximizes the discounted stream of utility subject to a constraint on his expenditures. Assume a constant rate of interest r. Let A_0 be the initial value of his assets, $S_1(0) = S_{10} \geq 0$, $S_2(0) = S_{20} \geq 0$, and let $w(t)$ be his exogenous earnings at time t. The wealth constraint can be written as:

$$\overset{\bullet}{A}(t) = w(t) + rA(t) - p_1 c_1(t) - p_2 c_2(t) - y(t),$$

where p_i is the price of c_i and $p_y = 1$ is the price of y. Prices are given and constant over time. The dynamic problem for the consumer is:

$$\max_{\{c_1(t), c_2(t), y(t)\}} \int_0^\infty e^{-\sigma t} u\left[c_1(t), c_2(t), y(t), S_1(t), S_2(t)\right] dt,$$

subject to:

$$\begin{aligned}\overset{\bullet}{S}_1(t) &= c_1(t) - \delta_1 S_1(t),\\ \overset{\bullet}{S}_1(t) &= c_2(t) - \delta_2 S_2(t),\\ \overset{\bullet}{A}(t) &= w(t) + rA(t) - p_1 c_1(t) - p_2 c_2(t) - y(t),\end{aligned}$$

and given initial conditions $A(0) = A_0 > 0$, $S_1(0) = S_{10} \geq 0$, and $S_2(0) = S_{20} \geq 0$. This problem can be solved using standard methods of optimal control. The current-value Hamiltonian for this problem is:

$$\begin{aligned}\mathcal{H}\left[c_1, c_2, y; S_1, S_2, A; \mu_1, \mu_2, q\right] &= u\left[c_1(t), c_2(t), y(t), S_1(t), S_2(t)\right] + \\ &\quad +\mu_1\left[c_1(t) - \delta_1 S_1(t)\right] + \mu_2\left[c_2(t) - \delta_2 S_2(t)\right] + \\ &\quad +q\left[w(t) + rA(t) - p_1 c_1(t) - p_2 c_2(t) - y(t)\right],\end{aligned}$$

where μ_1, μ_2, and q are the shadow prices of S_1, S_2 and A, respectively. We derive next the necessary conditions for optimality. The optimal consumption paths must maximize the Hamiltonian each period:

$$\begin{aligned}\mathcal{H}_{c_1} &= u_{c_1} + \mu_1 - qp_1 = 0, \\ \mathcal{H}_{c_2} &= u_{c_2} + \mu_2 - qp_2 = 0, \\ \mathcal{H}_y &= u_y - q = 0.\end{aligned}$$

The shadow prices must satisfy the adjoint equations:

$$\begin{aligned}\mathcal{H}_{S_1} &= u_{S_1} - \delta_1 \mu_1 = -\dot{\mu}_1 + \sigma\mu_1, \\ \mathcal{H}_{S_2} &= u_{S_2} - \delta_2 \mu_2 = -\dot{\mu}_2 + \sigma\mu_2, \\ \mathcal{H}_A &= rq = -\dot{q} + \sigma q.\end{aligned}$$

Lastly, we obtain the accumulation processes:

$$\begin{aligned}\mathcal{H}_{\mu_1} &= c_1 - \delta_1 S_1 = \dot{S}_1, \\ \mathcal{H}_{\mu_2} &= c_2 - \delta_2 S_2 = \dot{S}_2, \\ \mathcal{H}_q &= w + rA - p_1 c_1 - p_2 c_2 - y = \dot{A}.\end{aligned}$$

To guarantee sufficiency, in addition to utility being jointly concave in all variables and having the three initial conditions for the value of assets and the stocks of the two addictive goods, the following limiting transversality conditions are needed:

$$\begin{aligned}\lim_{t\to\infty} e^{-\sigma t}\mu_1(t)\left[S_1'(t) - S_1(t)\right] &= 0, \\ \lim_{t\to\infty} e^{-\sigma t}\mu_2(t)\left[S_2'(t) - S_2(t)\right] &= 0, \\ \lim_{t\to\infty} e^{-\sigma t}q(t)\left[A'(t) - A(t)\right] &= 0,\end{aligned}$$

for all feasible trajectories. Hence, the canonical system can be summarized by these conditions. This system of equations determines the dynamics of the model. The local stability properties of the above system are derived by linearizing it around the steady state and examining the corresponding characteristics roots. Linearization gives the following system:

$$\mathcal{A}\mathcal{X} + \mathcal{B}\overset{\bullet}{\mathcal{X}} = \mathbf{0},$$

where

$$\mathcal{A} = \begin{bmatrix} u_{c_1c_1} & u_{c_1c_2} & u_{c_1y} & u_{c_1S_1} & u_{c_1S_2} & 0 & 1 & 0 & -1 \\ u_{c_2c_1} & u_{c_2c_2} & u_{c_2y} & u_{c_2S_1} & u_{c_2S_2} & 0 & 0 & 1 & -1 \\ u_{yc_1} & u_{yc_2} & u_{yy} & u_{yS_1} & u_{yS_2} & 0 & 0 & 0 & -1 \\ u_{S_1c_1} & u_{S_1c_2} & u_{S_1y} & u_{S_1S_1} & u_{S_1S_2} & 0 & -\delta_1-\sigma & 0 & 0 \\ u_{S_2c_1} & u_{S_2c_2} & u_{S_2y} & u_{S_2S_1} & u_{S_2S_2} & 0 & 0 & -\delta_1-\sigma & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & r-\sigma \\ 1 & 0 & 0 & -\delta_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & -\delta_2 & 0 & 0 & 0 & 0 \\ -1 & -1 & -1 & 0 & 0 & r & 0 & 0 & 0 \end{bmatrix},$$

$$\mathcal{B} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \end{bmatrix}, \quad \mathcal{X} = \begin{bmatrix} c_1 \\ c_2 \\ y \\ S_1 \\ S_2 \\ A \\ \mu_1 \\ \mu_2 \\ q \end{bmatrix}, \text{ and } \mathbf{0} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}.$$

Let us try $\mathcal{X}(t) = e^{\lambda t}\mathcal{K}$, where $\mathcal{K}$ is a constant vector, as a solution to the system $\mathcal{A}\mathcal{X} + \mathcal{B}\overset{\bullet}{\mathcal{X}} = \mathbf{0}$. Given that:

$$\frac{d}{dt}e^{\lambda t}\mathcal{K} = \lambda e^{\lambda t}\mathcal{K},$$

and

$$\mathcal{A}e^{\lambda t}\mathcal{K} + \lambda e^{\lambda t}\mathcal{B}\mathcal{K} = \mathbf{0},$$

we have that $\mathcal{X}(t) = e^{\lambda t}\mathcal{K}$ is a solution if and only if λ and $\mathcal{K}$ satisfy $(\mathcal{A} + \lambda\mathcal{B})\mathcal{K} = \mathbf{0}$. This equation has a nonzero solution $\mathcal{K}$ if $\det(\mathcal{A} + \lambda\mathcal{B}) = 0$, that is if:

$$\begin{vmatrix} u_{c_1c_1} & u_{c_1c_2} & u_{c_1y} & u_{c_1S_1} & u_{c_1S_2} & 0 & 1 & 0 & -1 \\ u_{c_2c_1} & u_{c_2c_2} & u_{c_2y} & u_{c_2S_1} & u_{c_2S_2} & 0 & 0 & 1 & -1 \\ u_{yc_1} & u_{yc_2} & u_{yy} & u_{yS_1} & u_{yS_2} & 0 & 0 & 0 & -1 \\ u_{S_1c_1} & u_{S_1c_2} & u_{S_1y} & u_{S_1S_1} & u_{S_1S_2} & 0 & -\delta_1-\sigma+\lambda & 0 & 0 \\ u_{S_2c_1} & u_{S_2c_2} & u_{S_2y} & u_{S_2S_1} & u_{S_2S_2} & 0 & 0 & -\delta_2-\sigma+\lambda & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & r-\sigma+\lambda \\ 1 & 0 & 0 & -\delta_1-\lambda & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & -\delta_2-\lambda & 0 & 0 & 0 & 0 \\ -1 & -1 & -1 & 0 & 0 & r-\lambda & 0 & 0 & 0 \end{vmatrix} = 0.$$

The determinant of the matrix $\mathcal{A}+\lambda\mathcal{B}$ is a sixth degree polynomial in λ, $p(\lambda)$. For each root λ_j of $p(\lambda)$ there exists at least one nonzero vector $\mathcal{K}^j$ such that $(\mathcal{A}+\lambda_j\mathcal{B})\,\mathcal{K}^j = \mathbf{0}$. In order to assess the stability properties of the linearized system we need to examine the roots of this polynomial.[11] Real characteristics roots imply monotonic consumption paths whereas cycling in consumption occurs if the characteristic roots of the system are complex. The real parts of the complex roots determine whether the oscillations are damped, explosive, or persistent. If the real part of the complex root is negative, the waves are damped. The waves will be explosive if the real part of the complex root is positive. Limit cycles result if the real part of the complex root is zero.

We next provide numerical examples of each of these possibilities which show how this natural extension of the model where we allow for more than one addictive good delivers these four types of behavior.

2.2 Numerical Examples

It is first worth noting that the symmetry of the matrix $\mathcal{B}$ implies that if λ_i is a root of the polynomial $p(\lambda)$, then $\lambda_j = \sigma - \lambda_i$ will also be a root. A second aspect worth noting is that what we have in our linearized system is, broadly speaking, a Hessian modified by the time preference parameter σ and by some sign reversals that arise from the structure of matrix $\mathcal{B}$. Ryder and Heal (1973) recognize that this type of symmetry is useful in that it allows them to express the fourth order polynomial that they obtain in their setting as a quadratic polynomial in $(\lambda - \sigma/2)^2$. This allows them to assess the stability properties of the linearized system by solving directly the quadratic polynomial. Following a similar argument in our case, it may be shown

[11]These roots are the eigenvalues of the Jacobian $\mathbf{J} = -\mathcal{B}^{-1}\mathcal{A}$, that is the solutions to the characterist equation $\det(\mathbf{J}-\lambda\mathbf{I}) = 0$.

that $p(\lambda)$ may be written as a cubic polynomial in $(\lambda - \sigma/2)^2$. Given that:

$$p(\lambda) = \prod_{i=1}^{6} (\lambda - \lambda_i),$$

and using the fact that the roots come in pairs centered around σ, we have:

$$p(\lambda) = \prod_{i=1}^{3} \left(\lambda - \frac{\sigma}{2} - \lambda_i + \frac{\sigma}{2}\right)\left(\lambda - \frac{\sigma}{2} + \lambda_i - \frac{\sigma}{2}\right) = \prod_{i=1}^{3} \left[\left(\lambda - \frac{\sigma}{2}\right)^2 - \left(\lambda_i - \frac{\sigma}{2}\right)^2\right].$$

This representation is useful to assess the properties of the system by solving a cubic polynomial rather than a sixth order polynomial. In our case, however, we are simply interested in showing how monotonic consumption paths as well as different types of cycling in consumption can be readily obtained in this setting. It is thus sufficient to show that each possible case in terms of real (stable and unstable) and complex roots is feasible. The following are some examples:

A. Consider the diagonal Hessian, $u_{ij} = 0$ for all $i \neq j$, where:

$$u_{c_1c_1} = -1,\ u_{c_2c_2} = -3,\ u_{yy} = -5,\ u_{S_1S_1} = -7,\ u_{S_2S_2} = -9,$$

along with parameter values $\delta_1 = 0.9$, $r = 0.5$, and $\sigma = 1$.

For $\delta_2 = 0.4$, we obtain both real (stable and unstable) and complex roots: $\lambda_1 = -2.4933$, $\lambda_2 = -1.4519$, $\lambda_{3,4} = .5 \pm 1.9135 \times 10^{-3}i$, $\lambda_5 = 2.4519$, $\lambda_6 = 3.4933$. Note that the minuscule size of the complex roots imply that we are right at a Hopf bifurcation point.

For $\delta_2 = 0.9$, we obtain only real roots, two stable and four unstable: $\lambda_1 = -2.4933$, $\lambda_2 = -1.7271$, $\lambda_3 = .49863$, $\lambda_4 = .50137$, $\lambda_5 = 2.7271$, $\lambda_6 = 3.4943$. Modifications around these parameter values yield different combinations of stable and unstable real roots. For instance, decreasing the time preference parameter to $\sigma = 0.1$ yields three real stable roots and three real unstable roots. Similarly, it is straightforward to obtain any amount of stable and unstable roots for given σ by appropriately modifying δ_1 and δ_2.

B. Consider the same Hessian examined in case A, except that we add a non-diagonal element different from zero: $u_{c_1S_2} = 2$. It is then straightforward to obtain *any* feasible combination of roots except complex roots with a zero real part. For instance, for $\delta_1 = 0.1$, $\delta_2 = 0.1$, $r = 2$, and $\sigma = 0.1$, we obtain complex conjugates with positive and negative real parts, as well as one stable and one unstable real root: $\lambda_{1,2} = -2.0666 \pm .35216i$, $\lambda_3 = -1.9$, $\lambda_4 = 2.0$, $\lambda_{5,6} = 2.1666 \pm .35215i$. The same roots are obtained if we had chosen instead $u_{c_1 S_2} = -2$. Again, in the neighborhood of these parameters it is possible to obtain other interesting combinations. In particular, it is possible to find the pair of real roots arbitrarily close to each other by setting σ close to zero. Recall that roots come in pairs centered around σ.

C. Consider now the Hessian where $u_{ij} = 0$ for all $i \neq j$ except for $u_{c_1 S_2} = -1$, with diagonal elements::

$$u_{c_1 c_1} = -6,\ u_{c_2 c_2} = -0.7,\ u_{yy} = -8,\ u_{S_1 S_1} = -9,\ u_{S_2 S_2} = -10,$$

along with parameter values $\delta_1 = 0.1$, $\delta_2 = 2$, $r = 1.5$, and $\sigma = 4$. We obtain two complex roots with negative real part $\lambda_{1,2} = -3.99884 \pm 3.16919i$, one stable real root $\lambda_3 = -0.43427$, and three unstable real roots $\lambda_4 = 1.5$, $\lambda_5 = 2.5$, and $\lambda_6 = 4.43427$.

D. Consider the Hessian:

$$\begin{aligned} u_{c_1 c_1} &= -4,\ u_{c_2 c_2} = -7,\ u_{yy} = -2,\ u_{S_1 S_1} = -9,\ u_{S_2 S_2} = -2, \\ u_{c_1 c_2} &= u_{c_2 S_1} = u_{c_2 S_2} = -1,\ u_{c_1 S_1} = -0.5, \\ u_{c_1 y} &= u_{c_2 y} = u_{y S_1} = u_{y S_2} = 0,\ u_{c_1 S_2} = 2, \end{aligned}$$

and the parameter values $\delta_1 = 0.5$, $\delta_2 = 0.3$, and $r = 0.5$. Then, for $\sigma = 1$, we obtain only real roots, three stable and three unstable, while for $\sigma = 4$ we obtain two stable and four unstable real roots. For $\sigma = 5$, we obtain two complex conjugate roots with negative real parts ($\lambda_{1,2} = -0.741403 \pm 0.0388115i$), two positive real roots ($\lambda_3 = 2$, $\lambda_4 = 3$) , and two complex conjugate roots with positive real parts ($\lambda_{5,6} = 5.741403 \pm 0.0388115i$). Interestingly, for $\sigma = 4.886173$ the roots are $\lambda_{1,2} = -.744453 \pm 0.000045416i$, $\lambda_3 = 2$, $\lambda_4 = 2.886173$, $\lambda_{5,6} = 5.63063 \pm 0.0000454157i$; that is, the minuscule size of the complex part of the complex roots imply that we are right at two Hopf bifurcation points. Again, it is straightforward to obtain similar types of cases by appropriately modifying the depreciation rates and the interest rate around the selected parameters.

E. Lastly, we provide some examples of limit cycles. Consider a Hessian where

$u_{ij} = 0$ for all $i \neq j$ except for $u_{c_1 S_2} = -1$, with:

$$u_{c_1 c_1} = -6,\ u_{c_2 c_2} = -7,\ u_{yy} = -8,\ u_{S_1 S_1} = -9,\ u_{S_2 S_2} = -10,$$

along with parameters $\delta_1 = 0$ and $\delta_2 = 0$. The determinant is 0 when $r = 1$ or when $r = \sigma - 1$. In either of these cases *any* type of cycle is possible, that is the remaining roots can be complex with real part positive, negative, or zero. Moreover, when $r \neq 1$ and $r \neq \sigma - 1$, *any* type of complex root is also possible. In particular, persistent (limit) cycles arise when $\sigma = 0.1259$. For this preference parameter one of the roots is $\lambda = -1.4523i$.[12] As in the previous examples, similar cases may be obtained for values of parameters in the neighborhood of the selected values.

Another example where limit and any other type of cycles may be readily obtained is the case in which each element of the Hessian is -1: $u_{ij} = -1$ for all i, j. In this case $p(\lambda) = 0$ regardless of the values that δ_1, δ_2, r, and σ may take.

We conclude from these numerical examples that any configurations of optimal consumption policies are possible. In this sense, the theory of rational choice is capable of explaining cyclical consumption paths expressed as damped, explosive, or limit cycles. Persistent and generic oscillatory behavior may be perfectly rational without introducing a second stock for an addictive good and requiring certain specific properties.

These examples also show that consumption cycles are *not only* possible if a single consumption good accumulates two stocks of consumption capital. In other words, consumption capital that is commodity-specific need not imply consumption paths that are monotonic.[13] Moreover, this result means that cycles need not arise from intertemporal substitution effects as introduced in Ryder an Heal (1973), and exploited in Becker and Murphy (1988) and Dockner and Feichtinger (1993). Of course, the likelihood of cyclical behavior increases if adjacent complementarity is also present.

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[12] The determinant is $(1-r)(1+r-\sigma)\left(-720 + 976\lambda^2 - 336\lambda^4 - 976\lambda\sigma + 672\lambda^3\sigma - 336\lambda^2\sigma^2\right)$. When $r \neq 1$ and $r \neq \sigma - 1$, the four roots are $\lambda = \left(21\sigma \pm \sqrt{21}\sqrt{122 \pm 2\sqrt{59}i + 21\sigma^2}\right)/42$. The third root $(-/+)$ is $\lambda_3 = Ai$ when $\sigma = \left(-61 - i\sqrt{59} + 42Ai^2\right)/42Ai$. Hence, if we set $A = -61/42 = -1.4523$, we have $\sigma = \sqrt{59}/61 = 0.1259$.

[13] This result shows how the result in Dockner and Feichtinger (1993) concerning persistent cycles crucially depend on not having any non-addictive goods in the instantaneous utility function.

3 Discussion

Becker and Murphy (1998) extend their basic model of rational addiction to consider the case of one addictive good that builds into two stocks. For instance, eating may build into health and weight capitals as in Cawley (1999). This could explain cycles in overeating when the stocks have very specific properties in terms of differences in rates of depreciation and degrees of adjacent complementarity and substitutability. Critics in the literature have argued that such conditions are too onerous because two stocks need to be identified for each and every addictive good, and because even if they are identified they would have to have very specific conditions in terms of depreciation rates and degrees of complementarity and substitutability. The analysis in the previous section has shown how such conditions, while sufficient, are not needed when more than one addictive good enters into the utility function. This is important because different cyclical patterns seem pervasive in life, not only for the harmful habits and addictions reported in the economics and medical literature but also for beneficial goods and activities such as exercising, reading, listening to classical music, interest in cultural events, religiosity, and others. In addition to explaining how cycles can be generated under no stringent conditions, multiple addictive goods can explain why not all harmful and beneficial addictions end up abruptly. The analysis, therefore, offers a tractable framework that overcomes the main empirical difficulties brought against the model.

The analysis also confirms why multiple addictive goods are emphasized in the medical literature on addiction. In this literature, special care is given to characterize the patterns of multiple drug use before, during, and after treatment. For instance, standardized seven-drug urinalyses (UAs) are typically performed in subjects admitted to drug abuse programs where patterns of multiple drug use are classified using a classification system that includes several different combinations of weekly use of up to eight drug types.

The empirical evidence indicates that some harmful addictive goods are substitutes and some are complements with other addictive goods. For instance, heroin abusers commonly substitute other drugs for heroin such as marijuana, cocaine, and alcohol, or shift to less serious patterns of abuse after treatment. Cocaine is frequently used with alcohol and marijuana. Pre-treatment cocaine use is related to post-treatment cocaine use, but not to opioid use, while opioid users are more likely to migrate to cocaine use following treatment than cocaine users are to move in the opposite direction (e.g., Hubbard and Mardsen (1986) and Simpson and Marsh (1986)).[14] About three-quarters of cocaine abusers are also diagnosed with alcohol abuse or dependence (Roshenow et al. (1997)). Many subjects report the use of alcohol after ingesting cocaine to take the edge off of the cocaine high. Interestingly, as the theory of complements with multiple addictive goods predicts, this complementarity is successfully exploited in medical drug treatments. Disulfiram, a medical compound whose direct effect is to prevent alcohol drinking, is used to reduce the likelihood of *cocaine* use by making it impossible for the cocaine abuser to use alcohol in conjuction with the cocaine.

As briefly mentioned earlier, relevant evidence on substitutions among addictive goods comes from what are considered to be the two leading causes of preventable death in the United States and other developed countries: smoking and obesity. The evidence conclusively indicates that tobacco smoking reduces appetite, that smoking cessation produces weight gain, and that concerns about future weight gain help predict current smoking behavior. The weight-control benefits of smoking would appear to be greater in younger populations, the time that people typically initiate smoking. Survey and empirical evidence shows that teenage girls often smoke cigarettes to protect themselves from an excessive consumption of calories, with its feared weight-gain consequences, particularly when other measures such as dietary restraints have failed.[15] The majority of all smokers, not only teenagers, also appear to be concerned about postcessation weight gain. Pinto et al. (1999) conclude that various factors, including *anticipation* of weight gain and weight gain following previous quit attempts, were associated with smoking for weight control among the women they study. Flegal et al. (1995), Williamson et al. (1991) and others study the influence of smoking cessation on the prevalence of overweight in the United States. Borrelli and Mermelstein (1998) find that weight gain is associated with subsequent relapse among abstainers. Cycles both in weight and smoking in these and similar studies have a clear relationship and causality.[16] Yet, despite the apparent relationship between

[14]Tims et al. (2001) collect a number of related studies and further references.

[15]Crisp et al. (1998) find a strong relationship between cigarette smoking and body weight concerns, and an awareness by subjects of this link in their study of schoolgirls in London and Ottawa. Friestad and Klepp (1997) study of adolescents in Norway find that concern about body image and weight gain is an important determinant of the decision to take up smoking, particularly among women.

[16]Nearly 64.5 percent of the U.S. adult population, or more than 120 million, are overweight,

these two addictions and the conclusive neurobiological evidence, they have always been considered separately from each other in theoretical and empirical models in economics.

As is well known, a major way to distinguish rational addiction from myopic behavior is testing for the effects of *anticipated* future price changes on current consumption. No such effects are present in myopic and other non-rational models while these effects are present in rational addictions models because of the symmetry of compensated cross price effects. When more than one habit or addictive good coexist in the instantaneous utility function relevant implications arise for the econometric specification of the model. For instance, with two goods, anticipation of future price changes of one good may have an effect on the current consumption of the other good. In the context of the above discussion on smoking and obesity, current weight gain may arise not only from an anticipated decrease in the future price of food but also from the anticipated *increase* in the future prices of cigarettes. The fact that reinforcement implies that consumptions of an addictive good at different times are complements, and that different addictive goods may be complements or substitutes, may generate a rich set of challenging empirical problems.

Not only different cycles of consumption and cessation and relapse patterns are observed for harmful addictions but also many beneficial habits such as jogging, religiosity, music, work, standard of living, interest in sports, and others may exhibit different cycling patterns of consumption and relapse.[17] In this sense, since many beneficial goods and activities may have habitual and addictive characteristics, a rational choice framework with multiple goods would be relevant, more generally, to the theory of consumption with habit persistence. Additional empirical predictions arise in this framework with respect to cycles of consumption and patterns of relapse and cessation that do not arise when habits are studied in isolation or in the study of models of aggregate consumption.

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with 25.5 percent being obese, according to the National Institute of Health and the 1999-2000 National Health and Nutrition Examination Survey. Cigarette smokers have a lower average body weight than nonsmokers, and are less likely to be obese and overweight than never-smokers. In their review of the literature, Froom et al. (1998) conclude that on average sustained quitters gain about 5 to 6 kilograms in weight. Practically all studies find that the estimated weight gain after smoking cessation is retained for several years, and most that the gain is largely permanent (see also Williamson et al. (1991)).

[17]Interactions between harmful and benefitial habits and addictions have not been studied in the literature, but they are definitely possible and do merit empirical consideration.

Public policy implications of a multiple addictions framework are also relevant. After the rising use of illicit drugs observed in recent years, policy makers are beginning to consider the ripple effects of policies targeting *one* substance on the use of *other* substances in the area of substance control policy. For instance, it is argued that legislation proposed in the past few years calling for significant increases in the price of cigarettes as a way to discourage youths from smoking may have caused youths to substitute marijuana for cigarettes. Also, the rise in marijuana use rates during the last decade in college campuses in which tougher alcohol policies have been enacted has raised the question as to whether recent alcohol policies have had the unintended consequence of raising illicit drug use among the college population. Unfortunately, however, to date little empirical research has attempted to determine whether these and other addictive goods are economic complements or substitutes.[18] Moreover, the scarce empirical evidence available is often inconsistent and offers ambiguous findings.[19] The mixed results may in part be attributed to the fact that a theoretical framework for exploring the relationship between the demands for different drugs that are needed to guide empirical research and to inform policy discussions is sorely lacking. In this sense, the analysis in this paper shows how it will be crucial to study the possible interdependencies between different addictive or habitual goods, both in terms of stocks and flows of consumption, and thus the cross price effects for given goods and across *different* goods. Although the empirical challenge may be quite demanding in terms of data requirements, the appropriate empirical specification with multiple goods may turn out to be crucial in many settings.

The important debates over the effects of taxation and other forms of regulation, and over the impact of legalization of current illicit drugs have been revived in recent years as illicit drug use has increased in the face of increasing spending on drug prohibition strategies. A multiple addictions framework can help inform these policy debates, help understand the impact of prices and drug control policies, and help guide empirical research.

[18] The only exceptions are discussed in Chaloupka *et al* (1999b) and DiNardo and Lemieux (2001).

[19] For instance, initial studies concluded that alcohol and marijuana were economic substitutes (see also DiNardo and Lemieux (2001)), whereas subsequent articles find some evidence of complementarity (see Chaloupka et al. (1999b) and Williams et al. (2001)). Saffer and Chaloupka (1999) generally observe complementarity relationships between alcohol, marijuana, cocaine, and heroin. In contrast, Petry and Bickel (1999) find that valium, marijuana, and cocaine are weak substitutes for heroin. Pacula (1998) presents evidence that supports the gateway hypothesis for alcohol and marijuana.

Lastly, in many alternative approaches based in irrational behavior different preferences or personalities fight for control over behavior. However, the analysis also shows how weak wills, limited self-control, myopic discounting, and other forms of time-varying preferences and opportunity sets are not needed to understand why addictions can end smoothly or abruptly, and how different types of cycles in consumption may arise in a natural fashion. The Becker-Murphy model highlights the implications of multiple addictions. Of course, multiple addictions would also enrich the rational models with learning and regret (Orphanides and Zervos (1995)), with endogenous discounting (Orphanides and Zervos (1998)), and the variant of the Becker-Murphy model with environmental cues in Laibson (2001).[20] Likewise, they would also enrich alternative approaches based on irrational behavior. In this sense, cyclical behavior, relapse, and non-abrupt cessation patterns *alone* may not be sufficient to identify the basic underlying model.

4 Concluding Remarks

Addiction is a major challenge to sociology, neurobiology, public policy, economics, and the theory of rational behavior. As previous authors have stressed, we do not claim that all of the idiosyncratic behavior associated with particular kinds of addictions are consistent with rationality. However, a theory of rational addiction does explain well-known features of addictions and appears to have a richer set of additional implications about addictive behavior than other approaches. This paper brings attention to the natural role of multiple addictive goods in explaining the process of addiction. It shows how multiple addictive goods can further enrich the rational addiction models, and can enrich non-rational models as well. This apparently innocuous and natural extension proves sufficient to explain the two fundamental shortcomings that have been brought against the rational model with one addictive good under no stringent conditions. Of course, the likelihood of cyclical consumption and smooth cessation patterns increase if the sufficient conditions identified in Becker and Murphy (1988) are also met in a multiple addictions model.

[20] I thank Athanasios Orphanides for the reference to Orphanides and Zervos (1998), a model where probabilistic cycles readily arise.

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