

Essays on Addiction, Myopia, and Inconsistency

A dissertation submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy at George Mason University

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Spring Semester 2009
George Mason University
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Dedication

I dedicate this dissertation to my parents, JaeMoo Yoon and MyungBae Lee.

Acknowledgments

There are so many people whom I am indebted to. I first give my sincere gratitude to my advisor, Dr. Laurence R. Iannaccone. He not only taught and introduced me to the economics of addiction and religion, but also guided me throughout this entire process of completing this dissertation. I thank him for the encouragement, guidance and endless discussion. I am also grateful to other members of committee, Dr. Robin Hanson and Dr. William Bainbridge.

My parents, JaeMoo Yoon and MyungBae Lee, have supported me with patience and faith to make this dissertation possible. My sister, HeeKyung Yoon, and brother-in-law, HoSung Go, also have been always kind and supportive for my entire graduate study. I cannot thank my family enough for being the best companion along this long journey.

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Abstract

ESSAYS ON ADDICTION, MYOPIA, AND INCONSISTENCY

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George Mason University, 2009

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Chapter 1: The standard theory of intertemporal choice provides a simple but elegant way to analyze how an individual consumes over time. Addiction, however, is documented as one of numerous anomalies that the standard theory fails to explain. The models of habit-forming and compulsive consumptions have been suggested as the economic ways to analyze addiction. The first aim of this paper is to outline the economics of addiction as two approaches where each concerns different aspects of stationarity assumed in the standard theory; stationarity in the set of instantaneous preferences and in the system of intertemporal preferences. The former highlights the endogenous mechanics under which instantaneous preference evolves over time, while the latter emphasizes the relative difference in evaluating the trade-off among intertemporal preferences. While two approaches are typically viewed as distinctive, my review suggests otherwise. The second aim of this paper is to show that two seemingly contrasting approaches have a common interest of understanding the manner in which preferences are arranged over time and, in consequence, leads to addiction. In particular, I show that the model of habit-formation can be easily modified to describe compulsive consumption predicted by the intertemporal model with the hyperbolic discounting. I also suggest that the insights of the economics of addiction shed new light to the social welfare analysis with interpersonal inconsistency and

dependence and the gateway effect of addiction development.

Chapter 2: I consider a seemingly simple extension of the theory of rational addiction. In particular, this paper relaxes a critical assumption in rational addiction that the habit is ‘commodity-specific.’ A habit is called commodity-specific when (1) a habit is accumulated by a specific consumption and (2) the marginal rate of substitution of a consumption for a habit depends only on a particular pair of consumption and habit. By allowing the non-commodity-specificity, I study multiple addictions and find that contemporaneous relation among consumptions alters their addictiveness. The condition of rational addiction with the non-commodity-specificity shows that when a rational individual is addicted to multiple commodities, the concept of adjacent complementarity extends hierarchically to what I call ‘gross adjacent complementarity.’ I also find that the gateway effect exists when drugs are substitutes and an increase in the price of a gateway drug has the deterrent and migrant effects to other drugs, ascribable to the income and substitution effects.

Chapter 3: Recent efforts by economists have shown some success in researching religion-related behaviors in individual, group, and cultural level. How religion may affect substance use is an area where such efforts have been relatively at minimal, while the literature in sociology, psychology, and medicine has recognized a general stylized fact of the negative relationship between religion and substance use. This paper reviews a large literature in sociology, psychology, and medicine that notes a clear negative relationship between religion and substance use. To explain the relationship between the two, this paper relies on the rational addiction explanation on three features of harmful addiction. First, as the consumption capital from substance use is dissipated by religious practice, current substance use is much less enforced from past use. Second, as the satisfaction gap between a given level of substance use in past and today becomes narrower, higher level of past substance use leads to much less loss in the utility from current substance use. And third, the reduction or interruption in current substance use does not result in the reduction in utility. As the increase in religious practice causes three effects, an individual chooses to reduce substance use.

Chapter 1: Addiction, Myopia, and Inconsistency: A Critical Review

1.1 Introduction

The standard theory of intertemporal choice suggests that an individual increases, decreases, or evens consumption over time, depending on the relative size of the rate of time preference to the rate of interest. For instance, when the rates of time preference and interest are same, it predicts that an individual smooths and equalizes consumption intertemporally by allocating an equal amount of wealth to each period. Its predictions on intertemporal choice rest on the assumption of stationarity in preference; stationarity in the set of instantaneous preference famously defended by Stigler and Becker (1977) and in the system of intertemporal preference initially proposed by Samuelson (1937). The economics of addiction, of which empirical and theoretical literature is reviewed here, is the result of recognizing, relaxing, and extending two aspects of stationary assumption.

Before jumping to the discussion on the economics of addiction directly, it is useful to revisit the standard theory of intertemporal choice and discuss the implication of each aspect of stationary assumption. In it, an individual maximizes the lifetime utility, which is the sequential sum of a given set of utilities (i.e. *a stationary set of instantaneous preferences* such that $\dot{u}_c = 0$) discounted by a fixed rate of time preference (i.e., *a stationary system of intertemporal preference* such that $\dot{\phi}(t) = e^{-\rho t}$ where $\dot{\rho} = 0$). An individual solves

$$c^*(\cdot) = \arg \max_{c(\cdot)} \int_0^T u(c(t)) e^{-\rho t} dt \quad (1.1)$$

subject to

$$A_0 - \int_0^T p(t)c(t)e^{-rt} dt \geq 0, \quad A(0) = A_0, \quad \text{and} \quad A(T) \geq 0 \quad (1.2)$$

where $u(\cdot)$ is concave in c , p is the price of consumption, r is the rate of interest, and A_0 is the initial level of wealth. In its restrictive form, the price and the rate of interest are also assumed to be constant ($\dot{p} = \dot{r} = 0$), and it leads to the result that an individual increases consumption over time ($\dot{c}^* > 0$) when the rate of time preference is relatively larger ($\rho < r$), decreases ($\dot{c}^* < 0$) when smaller ($\rho > r$), and unchanges ($\dot{c}^* = 0$) when two rates are same ($\rho = r$). (See appendix B.2 for its derivation.)

The implications of two aspects of stationarity assumption are most clearly observable when other incentives to (dis)save except to consume are absent. It is when the rates of time preference and interest are same so that an individual avails a steady level of wealth to each period: When two rates are equal ($\rho = r$), the optimal consumption path is constant over time, the wealth is allocated equally, the marginal utility of wealth (as well as of consumption) unvaries, and the change in the present value of instantaneous utility only induced by the rate of time preference.

Unvarying marginal utilities with a constant consumption path reveals that the set of instantaneous preferences is stationary (i.e., stable tastes). It implies a constant utility with a given set of choices such that the levels of satisfaction are intertemporally independent. That is, the standard theory supposes that how much an individual would enjoy a *crème brûlée* tonight is neither relevant to past experience with it nor to the choice of dessert in future.

Furthermore, the change in the present value of instantaneous utility over time indicates that the system of intertemporal preference is stationary. An introspection suggests that the time position of an individual does not affect how future is evaluated and that a constant consumption path identified by the standard theory holds even when the choice is made at a later period rather than at the beginning of the period. That is, the standard theory supposes that Christmas Club, the device to avail the fund at a distant future otherwise not

available, has no meaningful role of enforcing saving that is voluntarily conserved anyhow. Thus, two aspects of stationarity assumption in the standard theory suppose that the choice is not subject to past experience or future consumption and that an individual is time-consistent.

The psychology of addiction teaches that addiction is associated with several distinctive features. Among them are *reinforcement* that previous experience or consumption stimulates the likelihood of the repetition; *tolerance* that increasing amounts of consumption are necessary to attain the same behavioral and subjective effects; and *withdrawal* that cessation of use activates the physical or mental disturbance (Kalant, 2001). They involve the dynamics that the standard theory is limited to address; for example, reinforcement implies a sort of learning in which the satisfaction of consumption depends on previous experiences. They are also why addiction is traditionally left as the subject that does not belong in the realm of economics: Friedman (1976 [1962], p. 13), for example, dismissed the economic inquiry onto “the formation of wants” as “the province of the psychologist.”

The economics of addiction is comprised of research programs that emphasize each aspect of stationarity assumed in the standard theory, so that the traditional limit in the domain of economics can be unbounded. The first purpose of this paper is to outline the economics of addiction as two contrasting views that either non-stationarity in instantaneous or intertemporal preference is the source of addiction. In doing so, I also identify several aspects in the economic theory of addiction that are crucial in understanding the addictive behavior.

In section 1.2, I address the first in which the consumption is regarded to be *habit-forming* and, in consequence, the set of instantaneous preferences is no longer stationary. When the consumption is habit-forming, the decision is not made out of vacuum, but the satisfaction of consumption at a period depends on past consumptions as well as present one. The habit-formation may be *myopic* or *rational*: The former appreciates the habit-formation only as an experience effect of learning about consumption and acquiring the taste for it, while the latter also emphasizes the effect of altering future well-beings.

The habit-formation may also be *commodity-specific* of an exclusive relationship between a consumption and its habit. The non-commodity-specificity of habit can shed new light on the economic analysis of addiction to the *gateway effect* of a sequential development in drug usage and the *multiple addictions* of understanding the contemporaneous relation among addictive goods. It is an approach that addiction is understood as a strong form of habit-formation where an individual is with *adjacent complementarity*.

The behavioral implication of strong addiction is also clarified by finding the *scaling* and *prolonging* effects . The scaling effect of being strongly addicted implies the emergence of multiple equilibria (or steady states) and individuals with a same preference structure may display two contrasting behaviors of abstention or addiction. It explains why the bimodal distribution among the population of being addicted becomes more likely to be observed as a good is strongly addicted. The prolonging effect, on the other hand, suggests that the gap between multiple equilibria widens as an individual is strongly addicted and that the change in the price of an addictive good may destabilize an equilibrium. The shift between the equilibria shows that a high price-elasticity (in the long-run) is expected when there is the change in the price of a strongly addictive good. I also provide the economic definitions of reinforcement, tolerance, and withdrawal.

Section 1.3 discusses the second that an individual is a (*quasi*-)hyperbolic discounter and has the nonstationary system of intertemporal preferences. The hyperbolic intertemporal preference implies that there are the *inner-conflict* of interests among the selves over time and the discordance of the planned and actual behaviors. If the consumption is habit-forming at the same time, the likelihood to drawn into addiction by the future-selves and the true cost of consuming an addictive good are underestimated. It is an approach that highlights the *regret* as the central feature of addiction.

An individual may be either *naive* or *sophisticated* about the *self-control problem* of the discordance between the planned and actual consumptions over time. If sophisticated, an individual is *pessimistic* that the future addiction is inevitable, but also may *incentivize* the future-selves not to overcome or directly attempts to reduce the *damage* from the self-control

problem. I show that how the interaction between three effects determines the degree of internalization of the *intertemporal-intrapersonal externality* and that a sophisticated individual may consume an addictive good more than a naive counterpart. The condition of adjacent complementarity for naive and sophisticated individuals is also provided.

My review of the economics of addiction shows that the essence of both approaches is on the question of how much an individual may internalize the intertemporal-intrapersonal externality and that the habit-formation only approach to addiction does not necessarily preclude the myopic behavior. In section 1.4, I develop a simple model of *myopic* and *quasi-myopic* habit-formation where the decision is predicated on a false assumption that the stock of habit remains constant over time or only partially predicted. After deriving the condition of adjacent complementarity for a quasi-myopic individual, it is shown that the *equivalent behavior* prescribed with the hyperbolic intertemporal preference structure emerges. This is a surprising result, indicating that both approaches have a common interest of understanding how the preferences are arranged over time. It also suggests a new way to understand the myopia and how an individual may behave strategically by adaptively learning about the alteration of preference structure. Section 1.5 concludes the paper with some future research suggestions.

1.2 Addiction as Habit-Forming Behavior

Among economists, there is a long tradition of recognizing the implication of stationarity in the set of instantaneous preferences that choices or experiences in the past are irrelevant in today's behaviors. Marshall (1961 [1890], p. 94) acknowledged "an implicit condition in this law" of diminishing marginal utility is "that we do not suppose time to be allowed for any alteration in the character or testes of the man himself." Tintner (1936, p. 60) studied the possibility of "commodities to which the individual in question may get more and more accustomed and the utility of which increases more rapidly the more the commodities have been consumed in the past." In spite of the recognition of its implication among economists, however, the interdependence of intertemporal choices was overlooked with the convenience

provided by the stationarity in the set of instantaneous preferences.

Since 1970s there has been the reverse of the trend. Following the criticism of Hicks (1965, p. 261) that independent “successive consumptions” are “nonsense” in economic growth theory, Wan (1970) and Ryder and Heal (1973) studied the optimal policy in an economy whose constituent has the endogenously-evolving taste with habit-forming consumption. In particular, Ryder and Heal (1973, p. 5) introduced the concept of *adjacent complementarity* with rational habit-formation that an individual chooses to have “a light breakfast and a substantial lunch” when “expects to receive a heavy supper”: Rational habit-formation implies that future consequence of consumption is internalized in the optimal growth plan of an economy.

In contrast to economic growth literature, myopic habit-formation was the focus in the study of consumer behavior. For example, Philips (1972), Pollak (1970) and von Weizsäcker (1971) discussed the property of the long-run dynamized system, implied by the short-run demand from the utility with the reference point: The reference point is a sort of inertia or necessary (i.e., minimum) amount of consumption that depends on past consumption and influences the level of current satisfaction. Habit-formation in the short-run demand and its long-run sister is myopic as “they are from a one-period utility function maximized subject to a one-period budget constraint” and do not take the future effects of altering subsequent preferences into account (Deaton and Muellbauer, 1980, p. 374).

The long-run behavior revealed under myopic habit-formation shows that it is easy for a myopic individual to become an addict: The theorem of increasing consumption sequence in von Weizsäcker (1971, p. 352) prescribes a process in which a myopic individual in the long-run becomes a heavy doer of substance despite the short-run preference to remain a light user at a given level of habit. It is the view that equates “habit-formation with the change in [the short-run] taste” although it is doubtful that the myopic choice to increase consumption sequentially and become an addict is the direct consequence of habit-formation (Iannaccone, 1984, p. 7). As will be discussed later, the myopia of failing to fully appreciate habit-formation is analogous to the myopia of the non-exponential

discounting of future utility in Strotz (1956) such that both lead to the time-inconsistent plan and intertemporal tussle from false assumptions about future. For earlier discussion of myopic habit-formation, see Gorman (1967) and Houthakker and Taylor (1970), which is refined further in El-Safty (1976a,b), Hammond (1976b), and Pollak (1976a, 1978).

Theory of Rational Addiction: It is ironic that addiction became a viable topic in economics because of the effort that defended economic models with stable tastes (i.e., stationarity in the set of instantaneous preferences). In challenging the interpretation that equates habit-formation with changes in taste, Stigler and Becker (1977, p. 89) introduced the concept of *consumption capital* and suggested an alternative that “partly translated unstable tastes into variables” in the household production model. Pollak (1978, p. 375) called the human capital model of past dependent behavior “a matter of semantics, not substance” with “no more explanatory power” as habit and consumption capital are essentially equivalent.

The innovative contribution of Stigler and Becker (1977), however, is not the distinction between habit and consumption capital, but is introducing the optimal intertemporal planning and internalizing the future effects of current consumption to the study of past dependent consumption. The optimal intertemporal planning with consumption capital was further developed by Iannaccone (1984, 1986) who recognized the relation between addiction and adjacent complementarity. I postpone the comparison of habit-formation and household production models as it resurfaces in the criticism of the optimal intertemporal model of habit-formation for its technical difficulty and complications.

Based on Stigler and Becker (1977) and Iannaccone (1984, 1986), Becker and Murphy (1988) proposed the theory of rational addiction. As it has become the yardstick in the economic study of addiction, it is natural to discuss the model of Becker and Murphy (1988) in detail first and then relate to others that also view addiction as habit-forming behavior. At its core, an individual with the lifespan of T searches for the optimal consumption path:

In general form, an individual solves the lifetime utility maximization problem defined by

$$c^*(\cdot) = \arg \max_{c(\cdot)} \int_0^T u(c(t), S(t)) e^{-\rho t} dt \quad (1.3)$$

subject to

$$\dot{S} = f(c(t)) - \delta S(t) \quad (1.4)$$

and

$$A_0 + \int_0^T w(S(t)) e^{-rt} dt \geq \int_0^T p(t)c(t)e^{-rt} dt \quad (1.5)$$

with the boundary conditions of

$$S(0) = S_0, S(T) = S_T \geq 0, A(0) = A_0, \text{ and } A(T) = A_T \geq 0. \quad (1.6)$$

Inner solutions are assumed from $\lim_{c_i \rightarrow 0} u_{c_i} = \infty \forall i$ uniformly in S and the rates of interest and time preference are same. For other assumptions and notational definitions, see appendix B.1.

The optimal solution of (1.3)-(1.6) leads to a seminal result that defines the condition of addiction and satiation for a rational (i.e., forward-looking) individual.

$$\text{sgn}(\dot{c}_i) = \text{sgn}\left(\frac{\delta_i + \beta_i^-}{f_{c_i}^i}\right) \text{sgn}(\dot{S}_i) \quad (1.7)$$

where

$$\text{sgn}\left(\frac{\delta_i + \beta_i^-}{f_{c_i}^i}\right) \begin{matrix} \geq \\ \leq \end{matrix} 0 \quad \text{as} \quad (2\delta_i + \rho)u_{c_i S_i} + f_{c_i}^i H_{S_i S_i} \begin{matrix} \geq \\ \leq \end{matrix} 0. \quad (1.8)$$

(β_i^- is a smaller eigenvalue from the linearized system of a current-valued Hamiltonian, H . Also see appendix B.2 for their derivation as well as that for (1.7) and (1.8).) A

rational individual with adjacent (or distant) complementarity is potentially addicted (satiated) to c_i . Adjacent complementarity implies addiction as an individual with adjacent complementarity increases future c_i as current c_i increases, and it happens when the left-hand side in (1.8) is larger than zero (i.e., “[t]he increase over time in the marginal utility of c_i would exceed the increase in full price”) (Becker and Murphy, 1988, p. 681).

Complexity and Future Observation: A common criticism of rational addiction is that the intertemporal optimization of forward-looking habit-formation is “exceedingly complicated” (Deaton and Muellbauer, 1980, p. 375).¹ Chua and Camerer (2004, p. 2) also question the computational ability of consumers to solve the intertemporal models that “clever economists could not solve...until a few years ago”, but instead suggest that consumers who learn about past experience of own and others can approximate the optimality of appreciating the change in future preferences. However, one cannot be comfortable with individuals who are either blind or ignorant about their future, and it is not clear what are actually being learned when past behaviors of own and others are observed.

To understand the computational challenge to an individual in solving the intertemporal model with habit-formation, let me rearrange the first order condition of H (i.e., (B.10) in appendix B.2) as

$$q(c_i) = u_{c_i} + \lambda_i f_{c_i}^i = \mu e^{-rt} p_i = \pi(p_i). \quad (1.9)$$

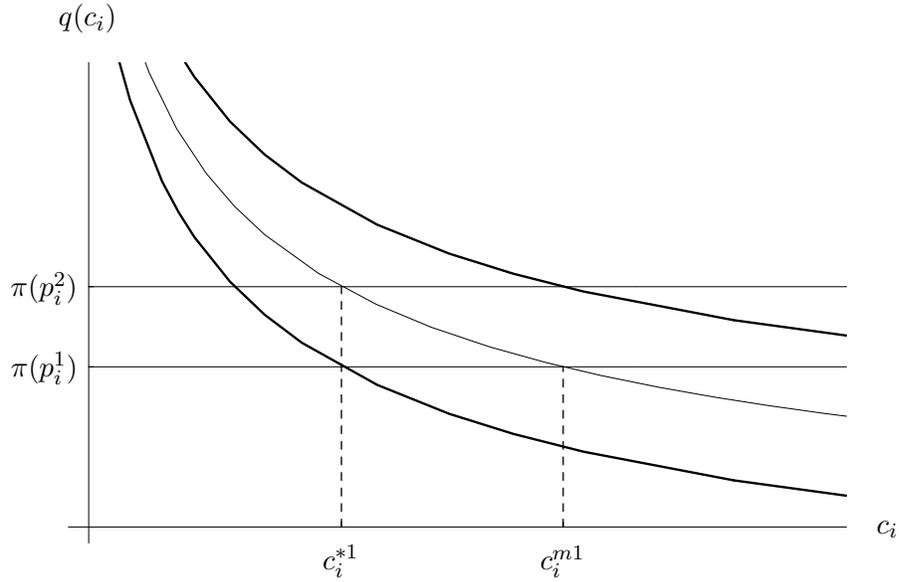
¹The complexity of rational habit-formation is also criticized to be unnecessary as myopic counterpart is already equipped to provide an observationally equivalent regression model. Based on the result in Spinnewyn (1979, 1981) that the reformulation of the wealth state equation makes intertemporal models with and without habit-formation formally equivalent, Phelps and Spinnewyn (1982, p. 20) argue that a myopic model of habit-formation “can be given a sound theoretical basis” to produce an equivalent regression model of rational counterpart. Pashardes (1986, p. 397) has already shown that observational equivalence only applies to “a special case where the short-run preferences are Cobb-Douglas” and that myopic and rational models of habit-formation are not observationally equivalent. However, there is a viewpoint that equates formal and observational equivalences and that both do not apply to the theory of rational addiction. For example, Chaloupka (1991) derives a rational regression estimator and uses it as the evidence for no equivalences of myopic and rational models of habit-formation (also see Chaloupka et al. (2000) and Chaloupka and Warner (2000)). The basis of observational equivalence, or the formal equivalence of intertemporal models with and without habit-formation through decentralization, however, is still valid in the theory of rational addiction. The opposing views on the equivalences seem to be rather affected by the ways in which experience effects are analyzed: For example, most models of endogenous taste assume myopic habit-formation, while models of consumption capital assumes rational one.

Without habit-formation, (1.9) becomes a familiar expression: $u_{c_i} = \mu e^{-rt} p_i$ of immediate marginal utility and direct marginal cost. Habit-formation effect of $\lambda_i f_{c_i}^i$ is an additional future utility and monetary cost of c_i to its immediate marginal utility: $q(c_i)$ is the long-run marginal utility of c_i . (Note that unlike Becker and Murphy (1988), I interpret the wedge as a part of the marginal utility but not of full price.) λ_i is positive when the habit is beneficial and is negative when harmful.

If β_i^- is assumed to be a stable root, $q(c_i)$ is monotonically decreasing and the condition implied by (1.9) can be diagrammatically presented as figure 1.1. It shows that habit-formation effect is essentially the *intertemporal-intrapersonal externality* of current consumption: Harmful habit has a negative externality of lowering the marginal utility in the long-run, while beneficial habit has a positive externality of raising one. The computational challenge is whether an individual can reasonably approximate the externality in future so that the level of current consumption properly internalizes it.

Forecasting and approximating the externality existing in future, however, is extremely difficult. For example, Allen and Carroll (2001, p. 268) consider an intertemporal problem with uncertain future income and find that adopting a consumption “rule-of-thumb” that reasonably captures the future flow of utility “requires an enormous amount of experience” of more than at least 10,000 of simulation-sequences. The difficulty of obtaining the consumption rule is “because the consequences of today’s actions are spread out over a very long time horizon” just as future externality of current consumption is spread out over time as well (Allen and Carroll, 2001, p. 256). Thus, it becomes doubtful that subjects in the experiment of Chua and Camerer (2004, p. 21) were able to approximate the optimality quicker (“about four lifetime sequences”) because they learned to be a better intertemporal optimizers or future forecaster.

The task of an individual, however, is not necessarily one in which an individual forecasts future externality and controls the level of consumption to internalize it. As figure 1.1 suggests, an individual can rather approximate the optimal consumption by becoming an efficient internal Pigovian taxer: As depicted in figure 1.1 and in case of harmful addiction,



A thin curve in the middle represents the immediate marginal utility of c_i , while the thicker curves represent the long-run marginal utilities. The long-run marginal utility is lower than the immediate marginal utility when the habit is harmful, and is higher when the habit is beneficial. The horizontal curves represent the direct marginal cost.

Figure 1.1: Immediate Marginal Utility, Direct Marginal Cost, and Long-Run Marginal Utility

an individual can increase the price from p_i^1 to p_i^2 to approximate the optimal consumption, instead of setting the quota of $c_i^{m1} - c_i^{*1}$ after understanding about future consequences. The question remains whether an individual is capable of levying a proper sin tax upon oneself, but a full disposition of such proposition is the beyond of this paper and would require another one.

A relatively simple rule-of-thumb of an internal price adjustment (alike what Friedman (1953) suggested as the process of trial and error), however, may be able to sufficiently internalize the externality that exists in future. For example, imagine a myopic individual who is completely blind about the negative externality of harmful addiction but who can compare the difference between planned consumptions of yesterday and today; $c_{ip}^m(\cdot; \bar{S}_i(\tau - 1))$ and $c_{ip}^m(\cdot; \bar{S}_i(\tau))$, respectively: Note that $\text{sgn}(c_{ip}^m(\cdot; \bar{S}_i(\tau)) - c_{ip}^m(\cdot; \bar{S}_i(\tau - 1))) = \text{sgn}(\bar{S}_i(\tau) - \bar{S}_i(\tau - 1))$ because of adjacent complementarity and that a myopic individual

who takes the habit to be constant in future also plans a constant consumption path. I suspect that the formulation of a multiplicative price parameter of a ratio, $\alpha_i(\tau) = c_{ip}^m(\cdot; \bar{S}_i(\tau))/c_{ip}^m(\cdot; S_i(\tau - 1))$, and its application to the direct marginal cost, $\pi(\alpha_i(\tau)p_i)$, would enable a myopic individual to approximate the behavior of a rational individual quickly: That is, $\lim_{\tau \rightarrow n} \alpha(\tau)p_i^1 \approx p_i^2$ for a smaller n in figure 1.1. In fact, this may be a sort of strategies that subjects in the experiment of Chua and Camerer (2004) have used.

Solving the intertemporal model with habit-formation is actually much more challenging than what figure 1.1 describes, and it would add further strain on formulating a consumption rule of becoming an efficient quota setter. To show how, let me revisit the first order condition of H and rigorously analyze it. As the shadow price of a habit ($= \lambda_i$ from (B.13)) is

$$\lim_{\tau \rightarrow \infty} \lambda_i(t) = \frac{u_{S_i}}{\delta_i + \rho} + \mu e^{-rt} \frac{w_{S_i}}{\delta_i + r}$$

in an infinite horizon ($T = \infty$) and if the rates of market interest and time preference are same ($\rho = r$), I may redefine (1.9) as

$$q(c_i) = u_{c_i} + \frac{f_{c_i}^i(u_{S_i} + \mu e^{-rt} w_{S_i})}{\delta_i + \rho} = \mu e^{-rt} p_i = \pi(p_i) \quad (1.9')$$

where $q(c_i)$ is again a long-run marginal utility of c_i (the sum of immediate and future utility/monetary cost of additional c_i) and $\pi(p_i)$ is the marginal (monetary) cost of c_i .

As equilibria exist when $q(c_i) = \pi(p_i)$ and the steady states are along the locus of $f^i(c_i) = \delta_i S_i$, the derivative of $q(c_i)$ is

$$q'(c_i) = \frac{\delta_i(\delta_i + \rho)H_{c_i c_i} + f_{c_i}^i((2\delta_i + \rho)u_{c_i S_i} + H_{S_i S_i} f_{c_i}^i)}{\delta_i(\delta_i + \rho)}. \quad (1.10)$$

There is a unique and stable equilibrium under distant complementarity or intertemporal independence as $q'(c_i) < 0$. However, under adjacent complementarity, the second term

in the right-hand side is positive and may be offsetting the negative first term. Since the concavity of H suggests

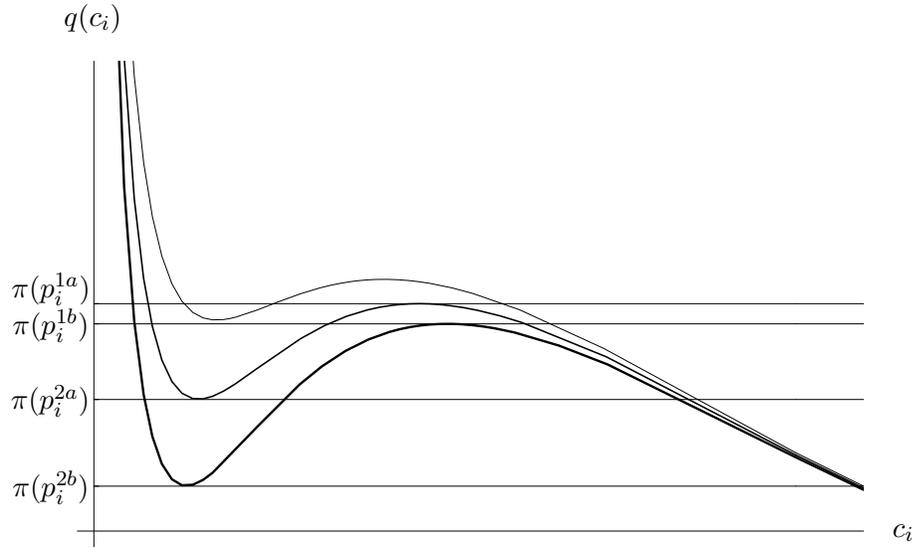
$$q'(c_i) < -H_{c_i c_i} \left(\frac{\rho}{2}\right)^2 > 0,$$

there is no assurance of $q'(c_i) < 0$, and there may be multiple equilibria. Figure 1.2 graphs $q(c_i)$ when $q'(c_i) > 0$ (i.e., the degree of addiction is relatively stronger).

The non-monotonic long-run marginal utility is evidently challenging to understand, and multiple equilibria implies that there are also multiple consumption rules of quota that are identically utility maximizing. While learning about the future utility flow of consumption rules, an individual observes the conflicting information that either increasing or decreasing consumption is equally utility enhancing, and the evaluation of consumption rules based on their future utility flow will be difficult. On the other hand, the price adjustment process of the trial and error essentially remains same. An individual does not need to concern about the existence of multiple equilibria as long as the price adjustment is not large enough to destabilize an equilibrium to another equilibrium, and receive a consistent information that either reducing or increasing internal price is utility enhancing.

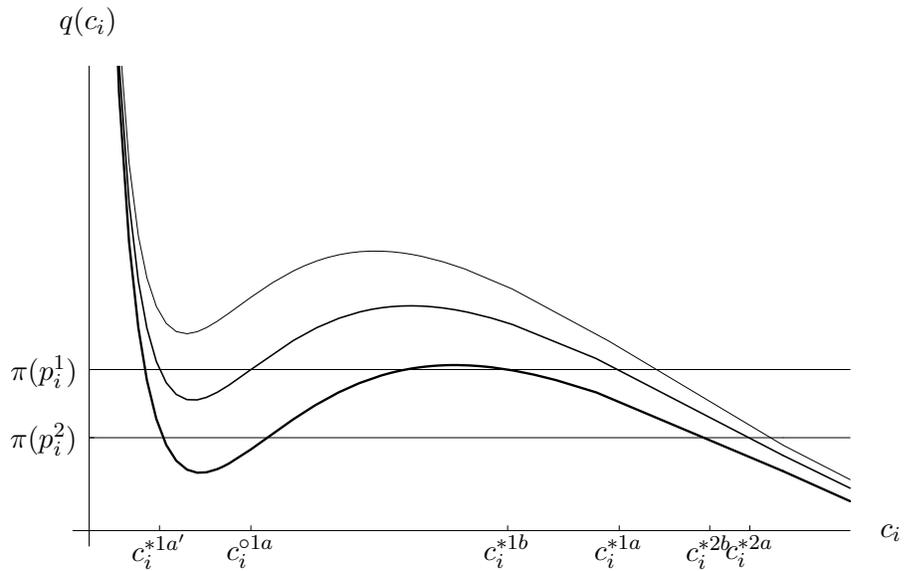
Scaling and Prolonging Effects: The derivative of the long-run marginal utility, $q'(c_i)$, is positive if and only if β_i^- is also positive (but less than $\rho/2$), and it implies that the possibility of multiple equilibria increases as the degree of addiction (i.e., adjacent complementarity) is stronger at a given level of c_i . (See (B.18) and (B.20) in appendix B.2.) Let me call this a *scaling effect* of addiction. Moreover, if the degree of addiction is stronger along the locus of $f(c_i) = \delta_i S_i$ by decreasing at a lower rate (i.e., the change in the degree of adjacent complementarity is smaller between c_i^{*1a} and c_i^{*1b}), the range of multiple equilibria increases when $q'(c_i) > 0$ or simply the long-run marginal utility diminishes at a lower rate when $q'(c_i) < 0$, which I call a *prolonging effect* of addiction.

Scaling and prolonging effects are the crux of analysis in the theory of rational addiction. For example, the compensated change in price leads to a larger change in consumption levels,



(a) Scaling Effect on Long-Run Marginal Utility when $q'(c_i) > 0$

Long-run marginal utility with different degrees of adjacent complementarity at a given level of consumption. Thicker curve represents a stronger degree of adjacent complementarity uniformly.



(b) Prolonging Effect on Long-Run Marginal Utility when $q'(c_i) > 0$

Long-run marginal utility with different degree of adjacent complementarity along the locus of steady states. Thicker curve represents a stronger degree of adjacent complementarity of diminishing at a lower rate.

Figure 1.2: Long-Run Marginal Utility and Rational Addiction when $q'(c_i) > 0$

had addiction been stronger through prolonging effect $-p_i^1 \rightarrow p_i^2$ leads to $c_i^{*1b} \rightarrow c_i^{*2b}$ rather than $c_i^{*1a} \rightarrow c_i^{*2a}$ in figure 1.2(b); the compensated change in price can lead to even a larger change in consumption, had originally been at an abstention level $-p_i^1 \rightarrow p_i^2$ can leads to $c_i^{*1a'} < c_i^{\circ 1a} \rightarrow c_i^{*2a}$ that is larger than $c_i^{*1a} > c_i^{\circ 1a} \rightarrow c_i^{*2a}$; and a bimodal distribution of consumption among individuals is more likely, had addiction been stronger through scaling effect – the bandwidth of $p_i^{1b} \leftrightarrow p_i^{2b}$ is larger than that of $p_i^{1a} \leftrightarrow p_i^{2a}$ in figure 1.2(b). Other results such as cold turkey can also be easily derived as well (e.g., a small reduction in consumption ($\Delta c_i < c_i^{*1a} - c_i^{\circ 1a}$) cannot destabilize an equilibrium, but only a large reduction ($\Delta c_i > c_i^{*1a} - c_i^{\circ 1a}$) can).

Becker and Murphy (1988) do not seem to be able to differentiate scaling and prolonging effects of addiction since their model of addiction relies on a quadratic utility function with a linear habit-formation process that implies a constant degree of adjacent complementarity when S_i changes. Although they acknowledge that multiple equilibria require higher order terms such as “a cubic term in S^3 with a negative coefficient added to a quadratic function,” different forms of stronger addiction, which are crucial in understanding the shape of the long-run marginal utility and demand system, are not distinguished. The quadratic utility with linear habit-formation process only in a pair of c_i and S_i , on the other hand, significantly simplifies the dynamics of intertemporal choice and automatically qualifies habit to be *commodity-specific*. It is probably why the commodity-specificity of habit is often ignored in the literature.

Commodity-Specificity of Habit: Habits are called commodity-specific if for each S_i there exists a unique commodity, call it c_i , such that f^i and u_{c_i}/u_{S_i} depends only on (c_i, S_i) (Iannaccone, 1986): That is, habit-formation process is *input-specific* and the utility of the pair is *subutility-specific*, and it also implies the utility and investment functions are separable in pairs of (c_i, S_i) . Thus, the production of a commodity is not directly related to the prices and habits of other commodities, though these prices and habits will affect the

fraction of wealth that is budgeted to it.²

The subutility-specificity has been the main focus since a consistent maximization explanation of binge requires the introduction of a secondary but satiating habit of a consumption. Based on the analysis of a consumption cycle over time in Becker and Murphy (1988), for example, Dockner and Feichtinger (1993, p. 257) relate the introduction of the secondary habit to the non-commodity-specificity, and find that the dynamic behavior of binge requires “two counterbalancing effect” of addiction and satiation. In particular, they model the binge as a limit cycle that the marginal rate of substitution of a consumption to a habit now depends on the triplet of (c_i, S_1, S_2) instead. It partially relaxes the subutility-specificity where the marginal utility of c_i is also a function of the secondary habit, but fails to address the implication of the input-specificity.

The input-specificity and the other aspect of subutility-specificity are also important since they establish one-to-one relation between a consumption and its habits within the utility and simplify the dynamic analysis considerably. However, they limit the condition of adjacent complementarity to a special case of (1.8) that examines only the first order effect from a habit on a consumption while the possible second and higher order effects induced by the related consumptions and their habits disappear. For example, consider a (seemingly) simple model of $n = m = 2$ that does not assume both aspects of commodity-specificity:

$$c_1^*(\cdot), c_2^*(\cdot) = \arg \max_{c_1(\cdot), c_2(\cdot)} \int_0^T u(c_1(t), c_2(t), S_1(t), S_2(t)) e^{-\rho t} dt \quad (1.3')$$

subject to

$$\dot{S}_1 = f^1(c_1, c_2) - \delta_1 S_1 \text{ and } \dot{S}_2 = f^2(c_1, c_2) - \delta_2 S_2. \quad (1.4')$$

In such a model, the marginal rates of a consumption for its habits and habit-formation process are also functions of the other consumption. Then the theory of rational addiction can be applied to several aspects of addiction, which have been ignored in the literature.

²The subutility-specificity in the pair of (c_i, S_i) is identical to the commodity production of $Z_i(c_i, S_i)$ in $u(Z_i(c_i, S_i), c_{j \neq i}, S_{j \neq i})$ such that Z_{c_i}/Z_{S_i} only depends in the pair of (c_i, S_i) .

The first is the *gateway effect* that “use of a drug lower in the sequence increases the risk of using drugs higher in the sequence” (Kandel, 2002, p. 4). Though Pacula (1997) already claims that the gateway effect can be modeled through the theory of rational addiction, how an individual initially without adjacent complementarity to a drug in a higher sequence is induced to be with adjacent complementary by consuming a drug in a lower sequence has not been studied. The question remains whether the increase in S_2 from c_1 can lead to a sufficient increase in the marginal utility of c_2 so that an individual is with adjacent complementarity with respect to c_2 as well.

The second is *multiple addictions* that Palacios-Huerta (2003a) recently studied. Although he shows the possibility of monotonic and cyclical consumption patterns within a consistent maximization, the dynamic behaviors (and numerical examples) in his model do not conform to the basic definition of rational addiction that “an increase in current consumption increases future consumption” (Becker and Murphy, 1988, p. 681). The study of multiple addictions, however, is quite difficult, since the contemporaneous relation among consumptions complicates the concept of adjacent complementarity. Without commodity-specificity, the contemporaneous relation of c_1 and c_2 interacts with the intertemporal complementarity of c_1 or c_2 , and the definition of adjacent complementarity needs to be readdressed.

The lack of a sound theory on multiple addictions is also troublesome, as already shown by contrasting empirical results in defining the economic relations of addictive goods. For example, Chaloupka and Laixuthai (1997) and DiNardo and Lemieux (2001) argue that alcohol and marijuana are economic substitutes, while Farrelly et al. (1999) and Williams et al. (2004) find them to be economic complements (also see Saffer and Chaloupka (1999) and Pacula (1998)). I suspect that conflicting results are from the complicated relation of addictive goods where the econometric specifications fail to differentiate the contemporaneous and intertemporal cross price effects.

Reinforcement, Tolerance, and Withdrawal: Citing the psychology of harmful

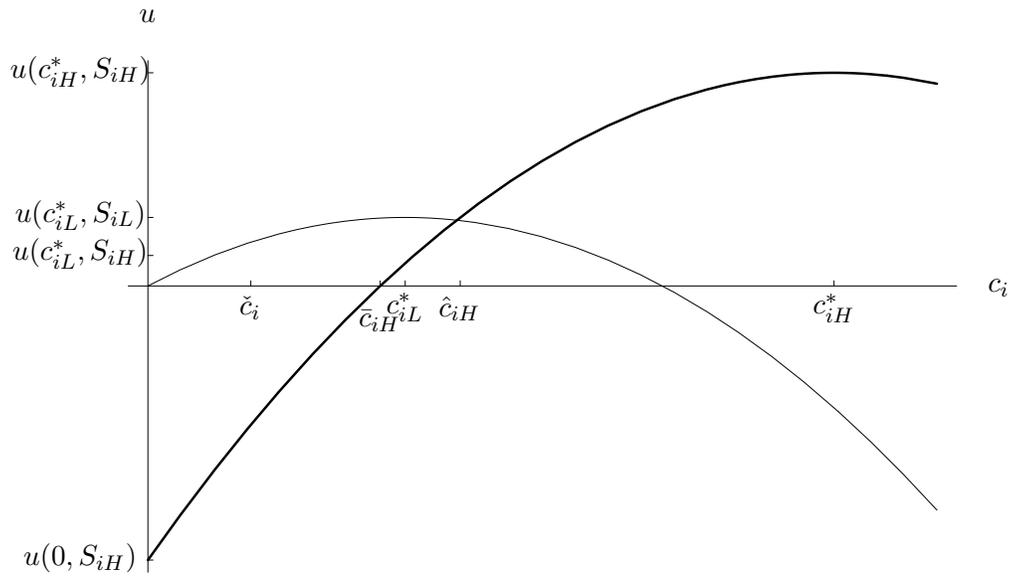
addiction, Becker and Murphy (1988, p. 682) interpret rational harmful addiction “as a form of tolerance” while relating reinforcement with adjacent complementarity. In a later study, Chaloupka (1991, p. 727) argues that the necessary conditions of the optimal solution define three features of harmful addiction mentioned in section 1.1; reinforcement as the raised marginal utility from the greater amount of past consumption and $u_{c_i S_i} > 0$, tolerance as the reduced future utility from a given level of consumption with a higher level of current consumption and $u_{S_i} < 0$, and withdrawal as the disutility from the cessation of consumption and $u_{c_i} > 0$. These are, however, poorly conceptualized economic definitions that are hard to swallow: For instance, withdrawal simply means that c_i is an economic good.

To provide better economic definitions of three features of harmful addiction, I examine the change in the value of instantaneous (i.e., short-run) utility as the habit grows over time. The condition of adjacent complementarity in (1.8) states that the optimal consumption grows when its habit grows. Since the habit measures past consumption of c_i , it implies a stimulation (i.e., positive experience) effect where the level of optimal consumption is larger as past consumption is larger: There is *reinforcement* of $c_{iH}^* > c_{iL}^*$ when $S_{iH} > S_{iL}$ since

$$\frac{\partial}{\partial S_i} [\arg \max u(c_i, S_i)] > 0 \text{ with } (2\delta_i + \rho)u_{c_i S_i} > -f_{c_i}^i H_{S_i S_i} > 0$$

where c_{iL}^* and c_{iH}^* are the optimal consumptions when S_{iL} and S_{iH} , respectively.

The shadow price of habit in (B.11) is negative when the habit is harmful, and the utility for $c \in (0, c_i^*)$ is lower with a higher level of habit. Since the value of utility at an optimal consumption with a given level of habit is lower when the habit is higher and the value of instantaneous utility with a given level of habit is also lower when a consumption of c_i is not at an optimal consumption, it implies that a higher level of consumption with a higher level of habit is required to obtain a same value of utility as one at an optimal consumption with a lower level of habit: There is *tolerance* of $\hat{c}_{iH} > c_{iL}^*$ when $S_{iH} > S_{iL}$



Two curves represent the values of instantaneous utility with two given levels of a habit where thicker curve is with a higher level of habit, $S_{iH} > S_{iL}$. Note following relations of $u_{c_i}(\check{c}_i, S_{iH}) > u_{c_i}(\check{c}_i, S_{iL}) > 0$; $u(\bar{c}_{iH}, S_{iL}) > u(\check{c}_i, S_{iL}) > u(\bar{c}_{iH}, S_{iH}) = 0$; $u(c_{iL}^*, S_{iL}) > u(c_{iL}^*, S_{iH})$; and $u(\hat{c}_{iH}, S_{iL}) < u(\hat{c}_{iH}, S_{iH})$. Reinforcement is represented by $c_{iH}^* > c_{iL}^*$ where $\frac{\partial}{\partial S} [\arg \max u(c, S)] > 0$; tolerance by $\hat{c}_{iH} > \hat{c}_{iL}$ where $u(c_{iL}^*, S_{iL}) = u(\hat{c}_{iH}, S_{iH})$; and withdrawal by $u(\check{c}_i, S_{iH}) < 0$ where $\check{c}_i < \bar{c}_{iH}$.

Figure 1.3: Reinforcement, Tolerance, and Withdrawal

since

$$u(c_{iL}^*, S_{iL}) = u(\hat{c}_{iH}, S_{iH}) \text{ with } u(\hat{c}_{iH}, S_{iL}) < u(\hat{c}_{iH}, S_{iH}) \text{ and } u(c_{iL}^*, S_{iL}) > u(c_{iL}^*, S_{iH}).$$

The marginal utility of c_i in (B.10) is positive, and it increases as the habit is higher with a positive experience effect in (1.8). Together with the disutility of harmful habit in (B.13), it implies that the cessation of consumption with a higher level of habit leads to a negative utility while one with a lower level of habit does not: There is *withdrawal* of $u(\check{c}_i, S_{iH}) < 0$ when $S_{iH} > S_{iL}$ since

$$\check{c}_i < \bar{c}_{iH} \text{ with } u_{c_i}(\check{c}_i, S_{iH}) > u_{c_i}(\check{c}_i, S_{iL}) > 0 \text{ and } u(\bar{c}_{iH}, S_{iL}) > u(\check{c}_i, S_{iL}) > u(\bar{c}_{iH}, S_{iH}) = 0.$$

This clarifies the claim of Becker and Murphy (1988) on reinforcement and tolerance with rational harmful addiction, while the concept of withdrawal is also defined economically. In figure 1.3, I present the concept of reinforcement, tolerance, and withdrawal diagrammatically.

Impatience, Myopia, and Rationality: Myopia is argued not to be ruled out, but to be a part of rationality in the theory of rational addiction. When the rate of time preference, ρ in (1.3), is larger, an individual is considered to “become more and more myopic” since future consequences of current consumption through its habit is more heavily discounted (Becker and Murphy, 1988, p. 683). In a similar spirit, “an infinite rate of time preference” is also used to describe myopic demand equations for cigarette in Chaloupka (1991, p. 729). In general, the definition of myopia in the theory of rational addiction is based on the degree of an individual’s impatience, in which a “fully myopic” (i.e., $\rho = \infty$) individual rationally “ignore[s] the future effects of a change in current consumption” (Becker and Murphy, 1988, p. 683).

In contrast, Iannaccone (1984) suggests a different notion of myopia. He notes that “the myopic formulation prohibits any kind of consistent intertemporal optimization, since plans

at each moment in time are predicated on false assumption” that “the future will be just like the present” and “changes in habits are treated as exogenous shocks.” (Iannaccone, 1984, p. 9, p. 99). However, this kind of myopic formulation about future also leads to addiction when habits “raise the marginal utility of its consumption relative to other commodities” just like the impatient formulation does (Iannaccone, 1986, p. 97). This seems to have contributed to regard both types of myopia to be equivalent. For example, in comparing myopic and rational models of addiction, Chaloupka and Warner (2000, p. 115) note that a myopic formulation of addiction “that future implications are ignored when making current decisions. . . implies an infinite discounting of the future”.

Their distinction, however, is important to be reconciled with, since myopia as blindfold about future implies an inconsistent planning that requires a continuous update of the change in the stock of habits where myopia as impatience does not. Furthermore, earlier myopic formulation in endogenous taste models relies on a similar definition of myopia as Iannaccone (1984)’s that “an individual does not recognize the impact of his present consumption on his future tastes” (Pollak, 1989, p. 71). This kind of “myopia in the context of experience effects” is also utilized to fulfill the second aim of this paper (Iannaccone, 1984, p. 97): The modification of habit forming model without invoking the nature of time preference can describe “spendthriftiness” in Strotz (1956, p. 165) or in more modern term, compulsive consumption for “immediate gratification” with hyperbolic discounting e.g., in O’Donoghue and Rabin (2002, p. 7), but also can assign different degrees of myopia to different habit forming consumptions.

The degree of impatience may be determined endogenously, changing an individual’s potential to addiction. Becker and Mulligan (1997) postulate a model of impatience in which an individual invests in “future oriented capital” that raises present value of future utility, while Orphanides and Zervos (1998) consider a model of addiction in which a harmful habit that reduces the utility (but does not increase the marginal utility) also makes an individual less patient. In both, the trade-off between current and future utilities plays a pivotal role in deciding an individual’s impatience and potential to addiction.

An individual in Becker and Mulligan (1997, pp. 738-9) displays “a complementarity between future utilities and weighting the future more heavily” and addiction that raises current utility in expense of future utility disincentivizes the investment in future appreciation capital: Addiction makes an individual more impatient, which, in turn, can lead to even more severe addiction. On the other hand, Orphanides and Zervos (1998) highlight a tension of two habit’s effects on impatience and disutility: The first is a heavier discounting of a given level of future cost making future consumption more desirable, and the second is a higher disutility for a given level of impatience reducing the overall utility. Without introducing the concept of adjacent complementarity, they are able to derive multiple steady states, similar to figure 1.2 of $q'(c_i) > 0$, where having a highly responsive impatience function to habit replaces the role of adjacent complementarity in creating multiple steady states: A highly responsive impatience to habit implies a different kind, but also a stronger form of intertemporal complementarity, making adverse effect of current consumption smaller and, in consequence, future consumption more attractive.

In reviewing the models of endogenous time preference, it is intentionally called to be the model of impatience. It is because an individual who is induced to discount the future heavier displays a time consistent behavior as long as the rate of time preference does “not depend on distance into the future”; the “recursive valuation” of the sequential estimation on how the not-conflicting self in next period will discount two periods ahead takes place; and the prediction of the future rate of time preference is not “systemically misestimated” (Becker and Mulligan, 1997, pp. 736-7). Or in the context of habit-formation, it implies that “the detrimental effect” of a habit-induced impatience is fully internalized within the trade-off optimization between current rewards and unbiased expected future costs, and an individual “need not ask to be tied for he does not fear the [immediate] temptation” (Orphanides and Zervos, 1998, p. 89). Now I turn to the discussion of an individual who needs to ask to be tied because of intrapersonal conflicts.

1.3 Addiction as Compulsive Behavior

Since the introduction of consumption capital to the household production model in Stigler and Becker (1977) to analyze addiction with a consistent utility maximization, the theory of rational addiction has been criticized to regard addiction as an intended behavior in which the internal struggle to control the consumption of addictive goods is assumed away. This is not surprising, given that the self-control literature has often highlighted addiction to illustrate the inconsistent planning caused by the nonstationary system of intertemporal preference.

Strategy of Self-Control: How an individual employs various strategies to prevent the inconsistent planning, however, has been the main focus of the self-control literature. Along with the work of Ainslie (1975, 1992) in experimental psychology, economists have followed the seminal work in Strotz (1956) to understand various control strategies to precommit or obtain a consistent plan when an individual is a hyperbolic discounter: To name a few, Pollak (1968, p. 207) examined the validity of the strategy of consistent planning and counterargued that the replacement of “the true discount function by a properly chosen exponential discount function” may not lead to the desired sophistication but the continuation of acting naively; Elster (1977, p. 494) provided the necessary criteria for employing the strategy of precommitment (i.e., self-binding) and analyzed it as “a precaution against inconsistency, not against irrationality”; and Schelling (1978, 1984) raised the importance of understanding the self-management strategy in alternating preferences and enumerated various practices of it.

Much of its application also have been on an area of the saving policy of an individual or economy, or the intertemporal allocation of wealth rather than the change in consumption basket: For example, Phelps and Pollak (1968) discussed a suboptimal intergenerational bequeath in an economy when each generation is imperfectly altruistic to future generations, which was later recognized in Laibson (1996) that the intergenerational imperfect altruism

implies a quasi-hyperbolic discounting of the future generations' well-being and that an analogous undersaving also occurs within a generation; Loewenstein and Prelec (1992) presented the intertemporal anomalies in the discounted utility (parallel to the expected utility anomalies) and developed a behavioral model of hyperbolic discounters that requires a higher compensation for a delayed award; Laibson (1997) examined a quasi-hyperbolic discounter with a limited access to the commitment strategy and argued for a consumption-income comovement and different marginal propensity to consume of liquid and illiquid assets; and Barro (1999) considered the neoclassical growth model with a quasi-hyperbolic discount function and the qualitative implication on the propensity to save in a short- and long-run.

In a similar spirit, Thaler and Shefrin (1981) developed a simultaneous planner-doer model of control problem, but without invoking the structure of time preference. The idea was to examine the control problem as conflicting interests of principle-agent within an individual "at a single point in time" and was applied to explain the variation in individual saving behavior as different methods of saving and income flow are given. In a later study, Shefrin and Thaler (1988) incorporated same planner-doer model into the life-cycle hypothesis, and suggested the mental accounting as a solution of inner conflict where an individual encodes the wealth into the accounts with different liquidity or cost to access. It was argued to enrich the life-cycle hypothesis and to explain how the frame of wealth may affect an asset's marginal propensity to consume and intertemporal allocation for its availability.

Until recent, much of the self-control literature seem to have generally concerned with the methods in which an individual resolves the inconsistent planning and their implication on the saving policy of how an individual or society allocates the wealth intertemporally.³

³There seems to be a genuine reason why this trend has continued and the explicit treatment of the self-control problem to the study of addiction has been somewhat limited until recent. The self-control problem generally implies that an individual consumes too much and save too little *now* and concerns a suboptimal intertemporal division of wealth. However, the problem of addiction is rather about particular goods or activities is developed to be consumed too much (i.e., being hooked) as the time elapses and once assumed. It is also difficult to provide on the rationale for an inconsistent individual (e.g., hyperbolic discounter) to be consistent on many consumptions (discounted exponentially so nonaddictive) while not on some (discounted hyperbolically so addictive) at the same time.

The review on the self-control literature in Rabin (1998) and Frederick et al. (2002) also documents the investigation on the internal/external precommitment technology and saving behavior as its main research topic.

Addiction and Regret: Winston (1980, p. 298), on the other hand, directly responded to the formulation of addiction in Stigler and Becker (1977) and criticized it for postulating an addict to be “happy” and without any regret. Instead he attempted to integrate the difficulty of self-regulating addiction, while maintaining the view that habit-formation alters the productivity of household commodity. In particular, an individual is considered to have a structure of flip-flopping dual preferences, of which each surfaces momentarily and together with the long-run preference, governs the consumption decision at a moment. The central feature of his model is the possibility of discordance in the consumption decisions prescribed by the long-run preference, which is the weighted sum of dual preferences, and whichever dual preference that surfaces momentarily. He argues that when the discordance exists, it is possible for the anti-market against addiction to emerge and for an individual to have a misconception about the true price of addiction and to seek the device of self-control against addiction.

I do not consider the critique of Winston (1980), also resonated in Akerlof (1991), to be fair and valid. For instance, consider an athlete who prepares for an Olympic three years from now. He may choose to stop the training as he felt that the hardship of training in next three years is simply too much. It is probable that he will not be happy about the decision when the Olympic game is aired in the TV and may shout “Gosh, I could have been there!” Yet, I do not see how an unhappy athlete who regrets the decision is different from an addict who claims to wish stopping but continues to consume addictive good, while Winston (1980) regarded them to be different.

Becker and Murphy (1988, p. 691) also recognized that the formulation of addiction in Stigler and Becker (1977) readily describes a negative-episodic initiation of addiction where an addict is unhappy, but “would be even more unhappy” had consuming the addictive

goods was prevented. Orphanides and Zervos (1995) examined a similar idea and considered a Bayesian updater who is uncertain about the potential of becoming an addict but learns about it through the experimentation with addictive good: When the likelihood of drawn into addiction is mistakenly underestimated, an individual risks to consume addictive good and becomes an addict. This also leads to an addict who regrets an earlier risky consumption and is unhappy about it, though this is another outcome of a consistent maximization.

While often overlooked in the literature, Winston (1980, p. 306) modified the model to recognize that “most addictive commodities work their effect not on the pleasures of their own consumption but on the production of other desirable activities or commodities.” That is, instead of making an individual to appreciate the consumption of addictive good, the habit-forming effect is assumed to alter the household productivity of nonaddictive commodity. This, in fact, alludes to the idea of relaxing the habit’s commodity-specificity assumption mentioned in previous section and the possible strategic behavior in engaging other activities to overcome the compulsive nature of addiction. This is one of areas that future research can contribute to the further understanding of addiction.

Theory of Compulsive Addiction: Based on recent development in the self-control literature, the view that an individual suffers from the nonstationary system of intertemporal preference for immediate gratification has been more explicitly applied to the study of addiction. Notable contributions are from O’Donoghue and Rabin (1999a, 2002) and Gruber and Köszegi (2001) that, like Winston (1980), maintained that the consumption of addictive good is habit-forming and an individual perceives its future consequences, but that an individual may have a nonstationary intertemporal preference of being a quasi-hyperbolic discounter; time-inconsistent individuals are divided into naive and sophisticated individuals depending whether the future self-control problems are recognized. One may call it as the marriage between the Beckerian and Strotzian approaches to study addiction.

O’Donoghue and Rabin (1999a) developed a binary-choice (i.e., hit and refrain) model of compulsive addiction and compared the behaviors of time-consistent, naive, and

sophisticated individuals. An individual is defined to be hooked if hit last period, and each type to follow the *perception-perfect strategy* to hit or refrain given the behavior in last period and the belief about future behaviors. The perception-perfect strategy of time-consistent and naive individuals at a given moment reflects the optimal future consumption path, although a naive individual will often revise the path in later periods. This is because a naive individual at a given moment makes the decision based on the incorrect belief that from the next period, a time-consistent individual will emerge as the future decision-maker. Yet, the perception-perfect strategy of a sophisticated individual reflects the strategic reaction and attempt to control against the correctly anticipated future behavior: A sophisticated individual may be pessimistic and hit now if future hitting is inevitable, but may refrain now if doing so provides the incentive to refrain in the future. The interplay of pessimism and incentive effects is at the crux of behavioral analysis and comparison of each type. For instance, a sophisticated individual may rather refrain now because it is only way to refrain later, although hitting now and refraining later lead to the highest lifetime utility and are chosen by a time-consistent individual. In a same situation, a naive individual hits now believing that it will be refrained later, but continues to hit later.

Although the analysis in O’Donoghue and Rabin (1999a) was elaborated further in Gruber and Köszegi (2001) and O’Donoghue and Rabin (2002), I use and review the model in Gruber and Köszegi (2001) as the representative theory of compulsive addiction. This is mainly because O’Donoghue and Rabin (2002) continued to formulate addiction as the binary-choice of hit and refrain, although an individual was instead defined to be hooked if the depreciation-weighted average of earlier hits is larger than a critical value. Letting earlier than last period hits influence the stock of habit (called “addictive level”) allows a richer set of results where quitting is no longer a one-time decision. However, it still restricts the study of addiction as the continuum of choices to hit rather than the choice to hit more at a given stock of habit or addictive level. This is problematic for the second purpose of this paper that requires a comparable model of compulsive addiction comparable to the modified model of habit-formation in section 1.4. Moreover, the interplay of pessimistic

and incentive effects continued to be an important factor in Gruber and Köszegi (2001).

Gruber and Köszegi (2001) developed a model of compulsive addiction that combines the nonstationary intertemporal preferences of a quasi-hyperbolic discounting to the instantaneous preferences in the theory of rational addiction. The quasi-hyperbolic discounting is originally from Phelps and Pollak (1968), which was later shown in Laibson (1997) that it mimics the general property of the hyperbolic discounting. An individual with the lifespan of T searches for the optimal consumption path, and I may summarize the lifetime maximization problem of each individual as

$$V(S_0) = \begin{cases} \max_{a(\cdot), c(\cdot)} U(0) + \sum_{t=1}^T \left(\frac{1}{1+\rho}\right)^t U(t) & \text{if stationary, and} \\ \max_{a(\cdot), c(\cdot)} U(0) + \beta \sum_{t=1}^T \left(\frac{1}{1+\rho}\right)^t U(t) & \text{if nonstationary} \end{cases} \quad (1.11)$$

where β captures the intertemporal aspect for immediate gratification of a time-inconsistent individual. The instantaneous utility is separable in consumptions that are habit-forming and non-habit-forming

$$U(t) = u(a(t), S(t)) + v(c(t)) \quad (1.12)$$

and (1.11) is subject to a simple (but modified) habit-formation process and a budget constraint at t .

$$S(t+1) = (1-\delta)(S(t) + a(t)) \text{ and } y(t) = c(t) + p(t)a(t) \quad (1.13)$$

The use of a momentary budget constant rather than a lifetime wealth constraint is to isolate “the effect of self-control problems for just addictive good” from the saving decision (Gruber and Köszegi, 2001, p.18). It also leads to an identical condition in the theory of rational addiction that when $p(t) = p(t+1)$, $y(t+1) = (1+r)y(t)$, and $r = \rho$, “consumption is constant in the absence of habit-formation effect” (Iannaccone, 1986, p. 97). I assume t_t is constant for all t .

A quasi-hyperbolic discounter is continued to be subdivided into naive and sophisticated individuals, and there exist three kinds of individual depending the system of intertemporal preference and the awareness of future self-conflict problems; only a sophisticated individual behaves strategically against the self-control problems in future. Letting the time subscript denotes the period of variables under the consideration, following Euler equation holds for a time consistent individual.

$$u_a(a_t, S_t) - p_t v'(c_t) = \left(\frac{1 - \delta}{1 + \rho} \right) (u_a(a_{t+1}, S_{t+1}) - p_{t+1} v'(c_{t+1}) - u_S(a_{t+1}, S_{t+1})) \quad (1.14)$$

which shows how much a is required to be undone to compensate the change at t . Similar to (1.9), the last term in RHS expresses the wedge that may be interpreted as a part of marginal utility or cost. For a sophisticated individual, following Euler equation holds for any $t < T$.

$$u_a(a_t, S_t) - p v'(c_t) = \left(\frac{1 - \delta}{1 + \rho} \right) \left(\left(1 + (1 - \beta) \frac{\partial a_{t+1}}{\partial S_{t+1}} \right) (u_a(a_{t+1}, S_{t+1}) - p_{t+1} v'(c_{t+1})) - \beta u_S(a_{t+1}, S_{t+1}) \right) \quad (1.15)$$

The derivation can be found in appendix B.2, which also includes the Euler equations for a naive individual.

As shown in (B.24), the decomposition of (1.15) indicates the interplay of pessimism and incentive effects that O'Donoghue and Rabin (1999a, 2002) identified and also an extra damage control effect: The damage control effect, while closely related to the incentive effect, refers to a distinctive effort of a sophisticated individual that even in the absence of incentive effect, a preemptive action is taken to lower the future stock of habit so that the welfare loss in the future from the perspective of current decision-maker is reduced.

The Euler equation of a sophisticated individual describes the best response when there is no access to the control technology, which is, in fact, abundantly available in the

market; e.g., “anti-markets” mentioned in Winston (1980, p. 299). That is, without the existence of such a market, the purpose of a sophisticated individual is to come up with a feasible plan that is actualized in the future, and the Euler equation expresses the concern of a sophisticated individual through pessimism, incentive, and damage control effects. Inversely, it is also indicative that the sum of three effects represents a sophisticated individual’s willingness to pay for the control technology to counter the uninternalized portion of the intertemporal-intrapersonal externality. This, together with “the cost of buying protection against a loss of will power” in Stigler (1987, p. 54), will decide the amount a sophisticated individual buys from the anti-market. Yet, Gruber and Köszegi (2001, p. 1286) dismissed the effectiveness of “market-provided self-control mechanisms” and examined the problem of a social planner who devises a Pigovian tax to correct the (marginal) self-control problem of a sophisticated individual.

Adjacent Complementarity in Compulsive Addiction: The economic definition of addiction rests on the concept of adjacent complementarity that “consumption of the good at different moments in time are complements” (Becker and Murphy, 1988, p. 689). Naturally, it leads to a question on how the condition of adjacent complementarity evolves as an individual becomes a quasi-hyperbolic discounter. The difference between the two determines the nature of compulsive addiction and highlights the departure of a hyperbolic discounter from his rational counterpart.

The condition of adjacent complementarity for a sophisticated individual was identified in Gruber and Köszegi (2001), but they continued to use a quadratic (instantaneous) utility function. As identified earlier in section 1.2, this restricts the economic analysis of addiction, and can be problematic in identifying possible scaling and prolonging effects. Furthermore, their condition of adjacent complementarity does not seem to accord with what is provided in the habit-formation literature. For instance, as $\beta \rightarrow 1$, the condition of adjacent complementarity for a sophisticated individual should approach the condition for a time-consistent (i.e., rational) counterpart (the Euler equation of every types converges

as $\beta \rightarrow 1$), but their condition of adjacent complementarity remains to be different.

Unlike Gruber and Köszegi (2001) and to derive a general condition of adjacent complementarity in compulsive addiction, I engage in an analogous derivation in Ryder and Heal (1973) that examines the change in the marginal rate of substitution of consumption between two periods as consumption at an in-between period changes. Letting $z(t)$ denote the (discounted long-run) marginal utility of consumption at t , the marginal rate of substitution of consumption between t_1 and t_2 is $R(t_1, t_2) = z(t_1)/z(t_2)$, and the condition of adjacent complementarity for compulsive addiction can be found from

$$R'(t_1, t_2; \tau) = \frac{z'(t_1, \tau)z(t_2) - z(t_1)z'(t_2, \tau)}{(z(t_2))^2}. \quad (1.16)$$

The sign of (1.16) shows the shift in preferences between t_1 and t_2 with the change in consumption at τ : For example, when $R'(t_1, t_2; \tau) > 0$ and $|\tau - t_1| < |\tau - t_2|$, there exists the complementarity of consumption between t_1 and τ (i.e., adjacent complementarity), and an individual increases consumption as past consumption is greater (i.e., addiction).

As derived in appendix B.2, a time-consistent individual is with adjacent complementarity when

$$(2\delta + \rho)u_{aS} + (1 - \delta)u_{SS} > 0, \quad (1.17)$$

which is, as expected, same condition in the theory of rational addiction (also see (1.8)). Moreover, (1.17) is also the condition of adjacent complementarity for a naive individual: This should not be surprising since a naive individual who is unaware of the self-control problem believes that future selves behave like a time-consistent individual. As we shall see shortly, however, it does not imply that a naive individual consumes optimally or naive and time-consistent individuals consumes same amount of addictive good. I now provide the condition of adjacent complementarity for a sophisticated individual: A sophisticated

individual is with adjacent complementarity when

$$((1 + \beta)\delta + \rho) u_{aS} + (1 - \delta)u_{SS} > 0. \quad (1.18)$$

(See appendix B.2 for the derivation.) (1.18) shows that a sophisticated individual, unlike a naive counterpart, considers the degree of self-control problem in displaying adjacent complementarity and becomes less prone to be addicted. This is precisely because a sophisticated individual fully understands that the increase in full price is also affected by the self-control problem or that the full cost of a also depends on (i.e., further discounted by) an extra variable, β . Indeed, a sophisticated individual is addicted only when the increase in the marginal utility exceeds the β -adjusted increase in full price and that the increase in current consumption leads to the increase in future consumption.

Intertemporal-Intrapersonal Externality: To understand the suboptimality of naive and sophisticated individuals and the role of awareness about the self-control problem, I examine the degree of internalization of intertemporal-intrapersonal externality. The optimal condition is described by a time-consistent individual's where the externality is fully internalized. However, naive and sophisticated individuals cannot fully appreciate the externality because of the self-control problem and an assumption of no access to the control technology. The awareness about the self-control problem also plays an important role in determining the divergence of the degree of internalization between naive and sophisticated individuals.

How much of intertemporal-intrapersonal externality is appreciated by each type is expressed as the size of the wedge in the long-run marginal utility, $z(t)$ in (1.16) (or more specifically from (B.25'), (B.29), and (B.31')), which is equated with the marginal (monetary) cost to determine the amount being consumed. Assuming far from the end of the horizon (so that there is the unique solution even for a sophisticated individual) and normalizing a time-consistent individual's to 1, the degrees of internalization for each type

are

$$\sigma_r = 1, \quad \sigma_n = \beta, \quad \text{and} \quad \sigma_s = \beta \left(\frac{1 - \delta}{1 - \beta\delta} \right) \left(\frac{\delta + \rho}{\beta\delta + \rho} \right), \quad (1.19)$$

respectively. They measure the proportion of the intertemporal-intrapersonal externality that is internalized by each type against what would be required to be optimal: When $\sigma < 1$, an individual overconsumes if habit is harmful, but underconsumes if beneficial. The degree of internalization is less zero for both naive and sophisticated individuals (unless $\beta = 1$), and it indicates that both types consume addictive good suboptimally.

Figure 1.4 graphs the degree of internalization of time-consistent, naive, and sophisticated individuals as the severeness of the self-control problem varies through β ; the self-control problem becomes more severe as $\beta \rightarrow 0$. A time-consistent individual consumes optimally and fully appreciates the future consequence of current consumption ($\sigma_r = 1$), while a naive individual only internalizes a β -portion of it ($\sigma_n = \beta$). The 45-degree lines in figure 1.4 show that a naive individual responds monotonically to the change in the severeness of the self-control problem. This is because a naive individual simply takes β as an uniformly applied discount factor but not as a cause of the self-control problem.

A sophisticated individual, on the other hand, correctly anticipates the self-control problem and purposely sets the present amount to consume against it, although when $\beta = 0$ or 1, a sophisticated individual behaves just like a naive counterpart as both types either do not internalize any portion of externality or behave like a time-consistent individual. As indicated by (B.24) and σ_s relative to σ_n in (1.19), when $0 < \beta < 1$, a sophisticated individual may or may not internalize a more portion of externality than a naive individual, depending on the relative size of pessimistic effect to the incentive and damage control effects. For example, a sophisticated individual understands that because of adjacent complementarity, there is an increase in the future consumption, becomes pessimistic about the future, and may indulge now. In contrast, a sophisticated individual with no access to the control technology also may influence the future consumption by adjusting the present amount to consume, which changes the stock level the future-selves inherit. That is, if

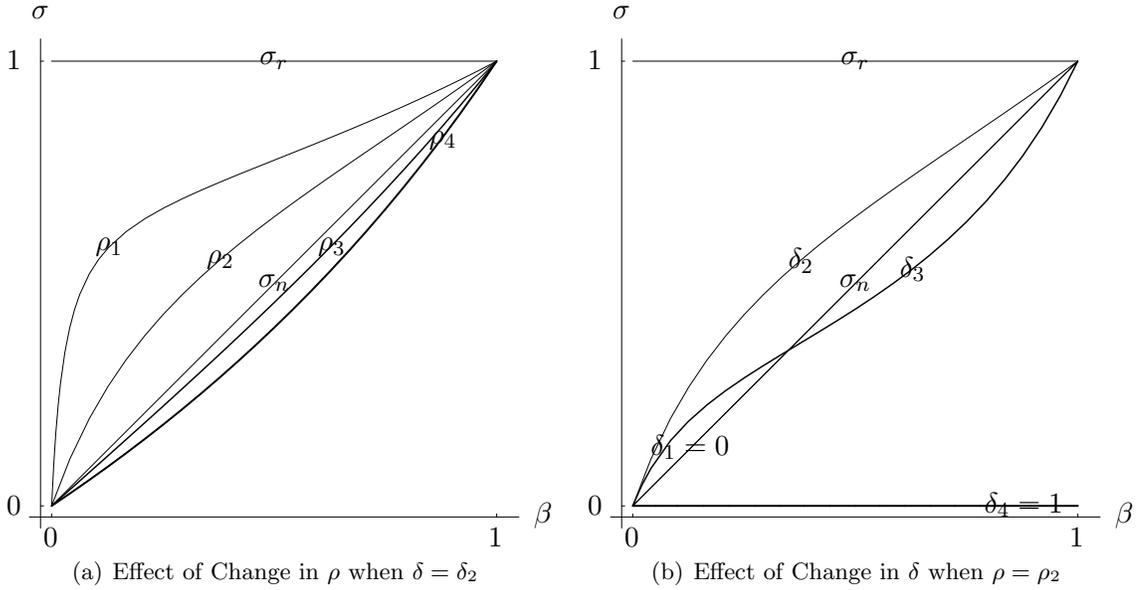


Figure 1.4: Degree of Internalization of Intertemporal-Intrapersonal Externality

the habit from current consumption does not fully dissipated, a sophisticated individual may reduce the consumption now to provide the incentive for the future-selves not to increase the consumption as much. Similarly but for a different reason, a sophisticated individual may also reduce the consumption now because the damage done by the control problem (i.e., the leveling effect from the change in the habit even in the absence of incentive effect) can be reduced. The interplay of three effects makes a sophisticated individual to respond differently from a naive counterpart, although only the “sophistication effect” about the self-control problem, or the interplay of the pessimism and incentive effect, is usually highlighted in the self-control literature (O’Donoghue and Rabin, 1999b, p. 111).

As indicated by ρ_2 and δ_2 curves in figure 1.4, when δ and ρ are relatively small, there is a usual case where a sophisticated individual internalizes more than a naive counterpart. This is because with the given level of the pessimistic effect from adjacent complementarity, smaller δ and ρ make the habit-formation effect last longer and there exist a larger motive to reduce the consumption: The incentive and damage control effect to reduce the consumption outweighs the pessimistic effect to raise it, and a sophisticated individual responds to the

self-control problem by internalizing a more portion of externality. However, as either δ or ρ increases, a lesser degree of externality begins to be internalized by a sophisticated individual. For example, when ρ increases, the habit-formation effect lasts relatively shorter, and the size of the incentive and damage control effects becomes smaller where the pessimism effect to raise the consumption may be even large enough to outweighs it. This is what is graphed in figure 1.4(a).

When δ changes, the habit-formation effect is affected similarly but only by changing the effectiveness of the mean to control the future consumption. For example, as the habit dissipates faster, $\delta_2 \rightarrow \delta_3$ in figure 1.4(b), a sophisticated individual has a lesser mean to affect the future consumption and the motive to reduce the current consumption is also weak. Only if the self-control problem is also relatively severe, the size of the incentive and damage control effects to mitigate overconsumption is larger than the pessimistic effect. When $\delta \rightarrow 1$, a sophisticated individual no longer possesses the mean to affect the future consumption, becomes only pessimistic about the future, and exacerbates overconsumption of not internalizing any portion of externality. Yet, as $\delta \rightarrow 0$, the influence of current consumption through the habit becomes perpetual, and a sophisticated individual behaves more like a naive one.

The theory of compulsive addiction, initiated by O'Donoghue and Rabin (1999a, 2002) and developed further by Gruber and Köszegi (2001), thus, introduces the possibility of failure to fully internalize the externality into the economic theory of addiction. In particular, an individual is postulated to be myopic because of the nonstationary (i.e., quasi-hyperbolic) system of intertemporal preferences that skews toward the present than the future. The question remains whether a similar behavior of a quasi-hyperbolic discounter is readily available in the theory of rational addiction. For instance, Becker and Murphy (1988, p. 684) claims that “fully myopic behavior is formally consistent with our definition of rational behavior,” although their definition of myopia is based on “strong discounts of future events” rather than the nonstationarity of intertemporal preferences. In next section, I examine the validity of the claim in Becker and Murphy (1988). Yet, I do so by employing

the seemingly-forgotten notion of myopia suggested in earlier habit-formation and addiction literature.

1.4 Synthesis of Two Theories

The main motivation of the theory of compulsive addiction is the question on the stationary system of intertemporal preferences assumed in the theory of rational addiction. Based on the evidence for the inconsistent planning in the experimental psychology literature, Gruber and Köszegi (2001, p. 1277) interpreted that the rationality of becoming addicted “imposes two assumptions on consumer behavior” of “forward-looking” and “time consistent” decision-making, and Kahneman (2003, p. 165) suggested that “the evidence of the grave deficiencies in taste prediction” is hardly reconcilable “with the extraordinary feats of hedonic prediction” from the rational-addiction model. Hopefully, my earlier reviews have already (at least implicitly) shown that the habit-formation only explanation of addiction does not necessarily preclude the behavioral properties suggested in the theory of compulsive addiction, which “marries this [quasi-hyperbolic] intertemporal preference structure with the instantaneous preferences . . . in the rational addiction model” (Gruber and Köszegi, 2001).

Hammond (1976a) already suggested that the nonstationarity in instantaneous preferences is closely related to the time-inconsistent planning problem as framed in Strotz (1956) or Pollak (1968). While treating two nonstationarity problems in instantaneous and intertemporal preferences in a unified framework, Hammond (1976a, p. 162) recognized that the essence of both problems is that “strict preferences get reversed over time” where any consistent planning, as in the rational addiction model, is predicated on a special circumstance of the coherent naive and sophisticated individuals. Yet, Elster (1977)’s claim to separate the two, the nonstationarity in instantaneous preferences “as merely the unfolding of a potential” and one in intertemporal preferences as “the progressive unfolding of an actual and unchanging attitude toward time”, still resonates and is the dominant view in the self-control literature. For example, O’Donoghue and Rabin (1999a, p. 176) regards

“study[ing] the implication of self-control problems alone” as the *sui generis* problem from the intertemporal preference structure, isolated from the underestimation in predicting the habit-formation effect.

To clarify how the nonstationary system of instantaneous preferences relates to the inconsistent planning, I develop a simple model of “myopic” or “quasi-myopic” habit formation “in the context of experience effect” that the habit does not change “as any predictable consequence of his own behavior” (Iannaccone, 1984, p. 97). Although Iannaccone (1984, p. 100) already provided its intuitive ground and suggested that “the aspects of addiction most strongly emphasized by Stigler and Becker (1977) ... emerge more easily and less ambiguously” in a myopic formulation in habit itself, it seems to have ceased to earn any interest among economists ever since the appearance of the rational-addiction model by Becker and Murphy (1988). By developing its simple model, I show that the myopic formulation in habit also leads to a similar addictive behavior that the theory of compulsive addiction describes. This is a somewhat surprising result, given much of discussion on the time-inconsistency has involved some kinds of non-constant and time-sensitive intertemporal preference structure.

Model of Myopic and Quasi-Myopic Habit-Formation: I first consider the model of ‘myopic’ habit-formation and its implication on addictive behavior. When an individual is myopic, the stock of habit is taken to be constant over time and as an exogenously determined variable in formulating the optimal planning, while actual stock of habit may evolve over time: This is a type of myopia discussed in earlier habit-formation literature, although much of the discussion has been concentrated on the derivation and stability of the long-run utility and demand functions at the steady state that is assumed to exist in the limit, and how they may correspond to the short-run utility function. To enhance its comparability, I maintain the model structure in the theory of compulsive addiction in

previous section. Then the lifetime maximization problem of a myopic individual at t is

$$V(S_0) = \max_{a(\cdot), c(\cdot)} U(0) + \sum_{t=1}^T \left(\frac{1}{1+\rho} \right)^t U(t) \quad (1.20)$$

subject to $S_{t+1}^* = S_t$ and the first in (1.13), although the evolution in actual stock of habit is governed by the first in (1.13).

This leads to a same optimal consumption planning observed in the standard theory of intertemporal consumption: As the habit is taken to be constant over time, the planned consumption path is also constant. Yet, contrary to the standard theory of intertemporal consumption, the consumption at t alters the stock of habit and an individual at $t+1$ needs to recalculate the optimal consumption path subject to S_{t+1} , but not to S_{t+1}^* . Indeed, a myopic individual displays the time-inconsistent behavior where in subsequent periods, new but still constant consumption paths are planned subject to the new stock of habit. The change in the stock of habit, however, is regarded as the exogenous shock, just like the change in price or income. Furthermore, as shown in appendix B.2, a myopic individual displays an increasing consumption profile over time or becomes addicted to a simply when

$$u_{aS} > 0, \quad (1.21)$$

and does not internalize any portion of the intertemporal-intrapersonal externality. This is because the amount to consume at t is arrived after falsely assuming that the habit remains constant and is not affected by own behavior, but not because an individual discounts the future infinitely as claimed in Becker and Murphy (1988) and Chaloupka (1991).

It is, however, improbable that a myopic individual will keep the false assumption that the stock of habit remains constant over time, given that new optimal consumption plans will continue to be recalculated. Instead, a myopic individual may notice the subsequent needs to change the plans, learn about the change in the stock of habit through them, and begin to ‘behave strategically’ against the expected change in the stock of habit. I call

that an individual is ‘quasi-myopic’ when such a strategic behavior is engaged: That is, a quasi-myopic individual who is in the middle of learning process foresees that momentarily the evolvement in the habit is governed by

$$S^\circ(t+1) = \eta(1-\delta)a(t) + (1-\eta\delta)S(t) \quad (1.22)$$

where $\eta \in [0, 1]$ represents the degree of an individual’s myopia at t that the η -portion of the change in the stock of habit induced by a_t is predicted. Whether a quasi-myopic individual may be able to mimic the behavior of a rational individual in the limit and what kind of learning process does so are interesting and important questions. For now, I only conjecture that a similar rule-of-thumb discussed in section 1.2 may enable a quasi-myopic individual to do so, and leave its full exposition for the future research.

The lifetime maximization problem of a quasi-myopic individual remains same as that of a myopic individual in (1.20), but now it is subject to (1.22) and the latter in (1.13). Like a myopic individual, a quasi-myopic individual also displays the time-inconsistent behavior as actual evolvement in the stock of habit is government by the first in (1.13), but not by (1.22). Letting the time subscript denotes the period of variables under the consideration again, following Euler equation holds for a quasi-myopic individual.

$$u_a(a_t, S_t) - p_t v'(c_t) = \left(\frac{1-\eta\delta}{1+\rho} \right) (u_a(a_{t+1}, S_{t+1}^\circ) - p_{t+1} v'(c_{t+1})) - \eta \left(\frac{1-\delta}{1+\rho} \right) u_S(a_{t+1}, S_{t+1}^\circ) \quad (1.23)$$

The derivation is also available in appendix B.2. An interesting feature of the Euler equation of the quasi-myopic individual is that the behavior of both, myopic and rational individuals, can be studied at the same time as special polar cases, myopia when $\eta = 0$ and rationality when $\eta = 1$: For example, a myopic individual does not consider any future consequence, the last term RHS in (1.23) becomes zero, and I have a same first order condition in the

standard theory of intertemporal consumption in section 1.1. This is one of the reasons why the theory of rational addiction does not necessarily preclude the myopia, as claimed in Becker and Murphy (1988).

To understand when a quasi-individual becomes addicted, I examine the condition of adjacent complementarity as already done for a quasi-hyperbolic discounter in section 1.3. Again, how the marginal rate of substitution of consumption between two periods changes when the consumption at an in-between period changes and which consumption at a period is closer to an in-between period show the direction of intertemporal shift in consumptions. I can, then, define the condition of adjacent complementarity and when a quasi-myopic individual is addicted. As derived in appendix B.2, a quasi-myopic individual is with adjacent complementarity and addicted when

$$(2\eta\delta + \rho)u_{aS} + \eta(1 - \delta)u_{SS} > 0. \tag{1.24}$$

As claimed above and expected, the condition of adjacent complementarity for a quasi-myopic individual can be easily extended to two special polar cases of myopia and rationality. Yet, in contrast to a result in section 1.3 that compares a sophisticated individual to time-consistent and naive individuals for their adjacent complementarity, a quasi-myopic individual is more prone to be addicted than a rational individual, but less prone than a myopic individual. Moreover, a quasi-myopic individual is with a lesser degree of adjacent complementarity and becomes weakly addicted at an increasing rate when more change in the stock of habit is predicted (i.e., a higher η), whereas there is an opposite and monotonic change in adjacent complementarity for a sophisticated individual when the self-control problem is less severe (i.e., a higher β).

Intertemporal-Intrapersonal Externality, One More Time: To compare the amount consumed by myopic and quasi-myopic individuals to ones with the self-control problem, I now consider the degree of internalization of intertemporal-intrapersonal externality when the decision is predicated on a false assumption that the stock of habit is constant over

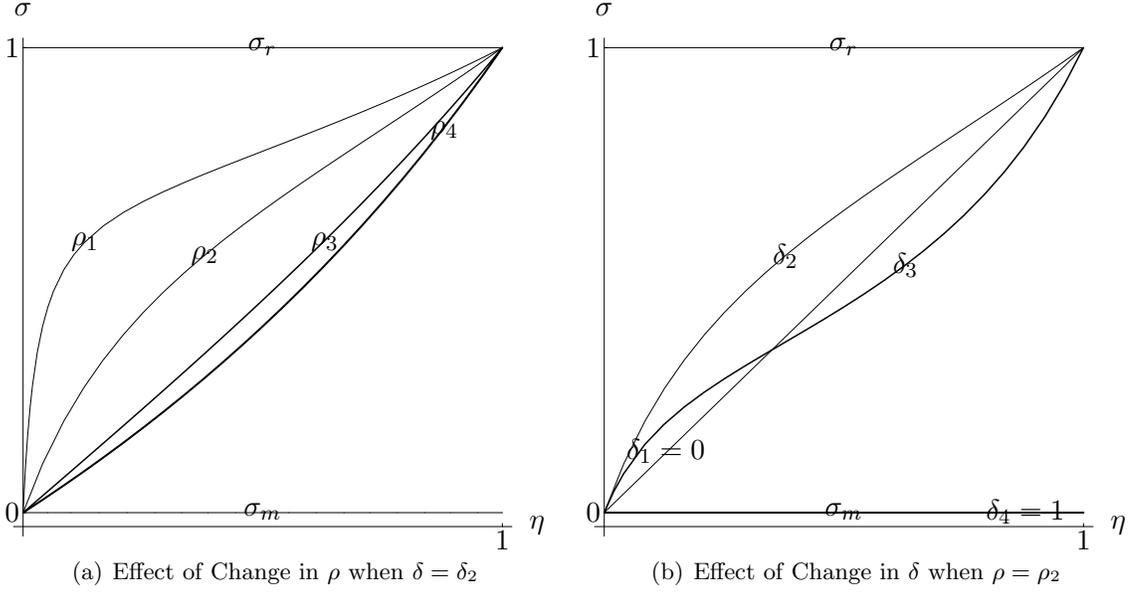


Figure 1.5: Degree of Internalization: Myopic and Quasi-Myopic Individuals

time or partially predicted. They are again expressed by the size of wedges in the long-run marginal utility, $z(t)$, and a quasi-myopic individual's is shown in (B.38') where $\eta = 0$ and $\eta = 1$ represent those of myopic and rational individuals, respectively. If the wedge of a rational individual is normalized to 1, the degree of internalization for each type are

$$\sigma_r = 1, \quad \sigma_m = 0, \quad \text{and} \quad \sigma_q = \eta \left(\frac{1 - \delta}{1 - \eta\delta} \right) \left(\frac{\delta + \rho}{\eta\delta + \rho} \right), \quad (1.25)$$

respectively. (1.25) shows that a myopic individual does not internalizes any portion of the future consequence induced by own behavior, while a quasi-myopic individual is able to internalize some portion of it depending on the size of η . Both type consume suboptimally by overconsuming if the habit is harmful but underconsuming if beneficial.

The comparison of (1.25) to (1.19) also suggests a somewhat surprising result that there is a *behavioral equivalence* between quasi-myopic and sophisticated individuals. For instance and as shown in figure 1.5, a quasi-myopic individual responds to the change in either ρ and δ just like a sophisticated individual does, and if a quasi-myopic individual is able to predict

a η -portion of the change in habit induced by own behavior, which happens to be same as the severeness of the self-control problem that a sophisticated individual needs to resolve (i.e., $\eta = \beta$), both individuals consume a exactly same amount of a . Yet, it is important to note that η reflects the effort of a quasi-myopic individual to solve the problem in predicting the evolvment in the stock of habit, whereas β states the severeness of self-control problem that a sophisticated individual faces.

The behavioral equivalence of quasi-myopic and sophisticated individuals also implies that both nonstationarities in instantaneous and intertemporal preferences are the attempts to understand how the preferences are arranged over time. The nonstationarity in instantaneous preferences emphasizes the endogenous mechanics that alters the future preferences through the habit-formation effect, while one in intertemporal preferences relies on the time-sensitive and exogenously-given discount function to evaluate the changes in the preference structure. The economic study of addiction is a particular application of either approach or combined one where an individual is found to be with adjacent complementarity and displays an age-increasing consumption profile.

Understanding the change in the intertemporal preference structure through the habit-formation, however, shed new light on how “the temporal discounting . . . is usually considered in most formal models by assuming time-separable preferences (Palacios-Huerta, 2003b, p. 252). For instance, by imposing a hyperbolic or quasi-hyperbolic discount function outside of the utility function, economists and psychologists have been able to formally model and study the time-inconsistent behaviors. Yet, doing so inevitably leads to an implicit result that consumers behave inconsistently to any good that they consume. The consideration of the intertemporal preference structure altered by the habit-formation, on the other hand, may enable economists and other social scientists to understand how the time-inconsistent behavior is endogenously created through the imperfect ability to predict the change in the stock of habit and is later resolved by adaptively learning about it.⁴ This

⁴For example, Ulysses may have been able to survive the last adventure by resisting the temptation while others did not because he learned to resist the temptation by sailing through the sirens without putting the wax in the ear.

seems to be more realistic approach, although I am not aware of any work done in this fashion.

1.5 Conclusion

In the paper, I review the economics of addiction and enumerate it into two distinctive approaches of concerning two nonstationarities in instantaneous and intertemporal preferences. The first regards the consumption to be habit-forming and the instantaneous preference is no longer stationary. Addiction is understood as a strong form of habit-formation where an individual is with adjacent complementarity. The second regards an individual to be a hyperbolic discounter where the system of intertemporal preferences is time-sensitive and nonstationary. By incorporating it into the habit-formation model, the regret is highlighted to be the central feature of addiction.

The economics of addiction is clarified in several ways. First, I identified that there are the scaling and prolonging effects when an individual is strongly addicted. They provide a clear rationale for the divergence in the usage of additive goods among the population and how an individual responds sensitively to the change in the price of an addictive good. Second, the economic definition of reinforcement, tolerance, and withdrawal is provided. Third, how the interaction of pessimism, incentive, and damage-control effects affects the degree of internalization of intertemporal-intrapersonal externality is clarified when an individual is sophisticated about the future self-control problem and the consumption is habit-forming. Three effects, together, suggest what it means to be sophisticated against the future self-control problem and how the sophistication can lead to even a higher level of addiction than a naive counterpart.

I also develop a simple model of myopic and quasi-myopic habit-formation where an individual has a false assumption about the change in the stock of habit. It leads to a somewhat surprising result that there is a behavioral equivalence between quasi-myopic and sophisticated individuals and that both economic approaches to addiction have a

common understanding on how the preference is arranged over time. The quasi-myopic habit-formation approach to addiction, on the other hand, suggests a new way to formulate the time-inconsistent behavior that has been dominantly studied through the hyperbolic intertemporal preference.

Several future researches can be suggested from the review and results presented in this paper. The recognition of the implication by the commodity-specificity of habit suggests that the economics of addiction has a profound insight on the the gateway effect and multiples addictions. They may contribute to the literature by suggesting the possible adverse effect in tax policy toward the addictive goods. The insight from the behavioral properties with habit-forming consumption may also shed new light on the social-welfare analysis, if the problem can be restated as an interpersonal problem instead of an intrapersonal one. As Pollak (1976b) suggested, an individual's well-being may depends on others, but how the insight from the habit-formation effect on the intrapersonal consideration may extend to the interpersonal issues remains as an open question.

Chapter 2: Multiple Habits and Addictions

2.1 Introduction

Consumers often become loyal to particular commodities and activities: Shoppers in a supermarket look for a particular brand that was purchased and consumed previously, travelers prefer a certain hotel chain and airline they used before, diners become regulars at a particular restaurant, and TV viewers watch the sequential episodes of a sitcom. Such behaviors are examples of time-dependent consumption that current consumption is affected by past consumption. More specifically they belong to a class of ‘habitual behaviors’ of “a positive relationship between current and past consumption” (Becker, 1992, p. 328).

To explain the habitual behavior and its stronger cousin, addiction, Stigler and Becker (1977), Iannaccone (1984, 1986) and Becker and Murphy (1988) propose the theory of rational addiction. At its core, an individual with the lifespan of T searches for the optimal consumption path by solving a lifetime utility maximization problem. The problem is defined by

$$\max_{c(\cdot)} J(c(\cdot), S(\cdot)) \stackrel{\text{def}}{=} \int_0^T u(c(t), S(t)) e^{-\rho t} dt \quad (2.1)$$

subject to

$$\dot{S} = f(c(t)) - \delta S(t) \quad (2.2)$$

and

$$A_0 + \int_0^T w(S(t)) e^{-rt} dt \geq \int_0^T p(t) c(t) e^{-rt} dt \quad (2.3)$$

with the boundary conditions of

$$S(0) = S_0, S(T) = S_T \geq 0, A(0) = A_0, \text{ and } A(T) = A_T \geq 0. \quad (2.4)$$

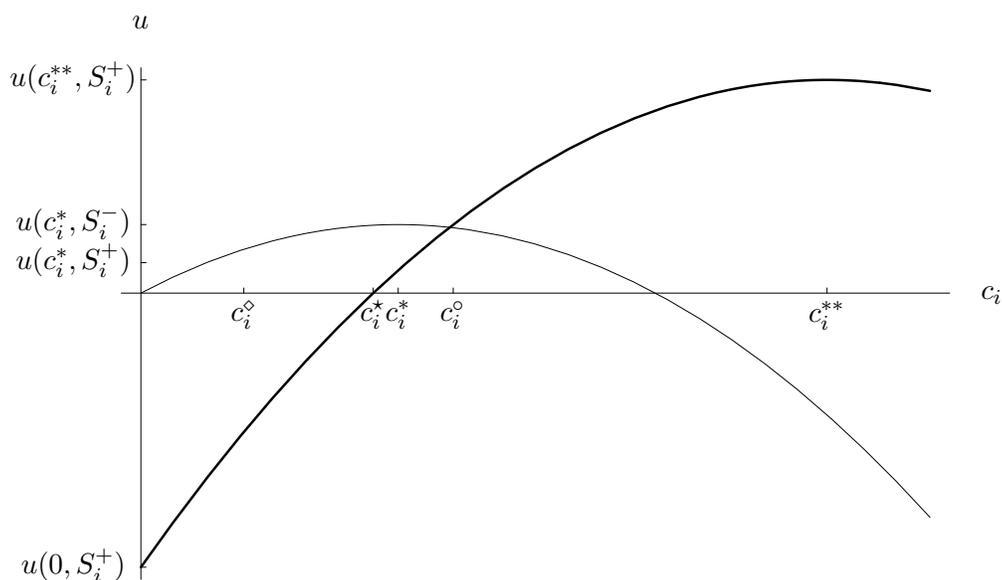
$u(\cdot) \in C^{(2)}$ is concave in c and S ; $c(t) \in \mathbb{R}^m$ and $S(t) \in \mathbb{R}^n$ are vectors of commodities being consumed and their habits generated at t , respectively; ρ is the rate of time preference; $f^i \in C^{(1)}$ is non-negative and non-decreasing in c ; δ is a diagonal matrix with $\delta_i \geq 0$, and δ_i is the depreciation rate of S_i ; $p \in \mathbb{R}^m$ is the price vector of c and $\dot{p} = 0$; $w(\cdot) \in C^{(2)}$ takes a same concave argument of $u(\cdot)$ in S ; and r is the interest rate.

This leads to a seminal result that defines the condition under which a myopic or rational (i.e., forward-looking) individual becomes an addict: For a myopic individual there is a positive habit-formation effect on current marginal utility, and for a rational individual there is ‘adjacent complementarity’ where a positive habit-formation effect on current marginal utility is sufficiently large enough to offset the habit’s possible adverse effect on future price (or utility).¹ Moreover, the rational approach to addiction captures three features of harmful addiction noted in psychology; withdrawal, tolerance, and reinforcement. I may present three effect graphically as in figure 2.1, and they can be specified as

$$\begin{aligned} u_{c_i}(c_i, S_i^+) > u_{c_i}(c_i, S_i^-) &\rightarrow \text{reinforcement} \\ c_i^\circ > c_i^* &\rightarrow \text{tolerance} \\ u(c_i^\circ, S_i^+) < 0 &\rightarrow \text{withdrawal} \end{aligned} \quad (2.5)$$

where $S_i^+ > S_i^-$, $u(c_i^\circ, S_i^+) = u(c_i^*, S_i^-)$, $0 \leq c_i^\circ < c_i^*$, and $u(c_i^*, S_i^+) = 0$. Reinforcement is defined by the raised marginal utility from the greater amount of past consumption; tolerance by the reduced future utility from a given level of consumption with a higher level

¹Wan (1970) and Ryder and Heal (1973) explains adjacent complementarity by an example that an individual chooses a heavy lunch instead of a heavy breakfast when expecting to have a heavy dinner.



Two curves represent the values of instantaneous utility with two given levels of a habit. The thicker curve is with a higher level of habit, $S_i^+ > S_i^-$. Note following relations of $u_{c_i}(c_i, S_i^+) > u_{c_i}(c_i, S_i^-)$; $u(c_i^*, S_i^-) > u(c_i^{\circ}, S_i^-) > u(c_i^*, S_i^+) = 0$; $u(c_i^*, S_i^-) > u(c_i^*, S_i^+)$; and $u(c_i^{\circ}, S_i^-) < u(c_i^{\circ}, S_i^+)$. Reinforcement is represented by $u_{c_i}(c_i, S_i^+) > u_{c_i}(c_i, S_i^-)$ where $S_i^+ > S_i^-$; tolerance by $c_i^{\circ} > c_i^*$ where $u(c_i^{\circ}, S_i^+) = u(c_i^*, S_i^-)$; and withdrawal by $u(c_i^{\circ}, S_i^+) < 0$ where $0 \leq c_i^{\circ} < c_i^*$ and $u(c_i^*, S_i^+) = 0$.

Figure 2.1: Reinforcement, Tolerance, and Withdrawal

of current consumption; and withdrawal by the disutility from the cessation of consumption with the greater amount of past consumption. Becker and Murphy (1988, p. 682) also note that tolerance reflects harmful (but not beneficial) addiction and that “[r]einforcement is closely related to the concept of adjacent complementarity.”

The results in the rational approach to addiction rest on several implicit and explicit assumptions, and many later economic studies of addiction have employed the strategy of relaxing those assumptions. For example, Gruber and Köszegi (2001) extend the theory of rational addiction by incorporating the quasi-hyperbolic intertemporal preference structure. While the basic logic of the rational approach that people are forward-looking and respond to the change in future price is confirmed empirically, they recognize an additional internal health cost if an individual is with the quasi-hyperbolic intertemporal preferences and displays the inconsistent planning. It leads them to argue that a higher level of the ‘Pigouvian tax’ is necessary to correct not only the interpersonal externality, but also the

intertemporal-intrapersonal externality (i.e., internality) from harmful addiction.

The assumption that motivates this paper is the ‘commodity-specificity’ of habits. Habits are called ‘commodity-specific’ when

1. $f^i(c)$ is a function of only c_i so that the accumulation of S_i depends solely on (c_i, S_i) ,
and
2. the marginal rate of substitution of c_i to S_i , u_{c_i}/u_{S_i} , depends solely on (c_i, S_i) .

The commodity-specificity implies that a habit, S_i , is the only channel in which past consumption of c_i is measured in the instantaneous utility, and that the change in the marginal rate of substitution between past and current consumptions of c_i is independent from other consumptions and habits ($c_{j \neq i}$ and $S_{j \neq i}$).

As shown in section 2.3 and technically, the commodity-specificity diagonalizes the sub-matrices in the Jacobian and significantly simplifies the dynamic system. Intuitively, the commodity-specificity let the economic analysis of addiction be concentrated on whether past consumption of c_i , only channeled through a habit, S_i , raises current consumption of c_i . At the same time, however, it inevitably restricts the applicability of the rational choice approach to addiction by suppressing the possibility of multiple addictions (or satiation) that a habit-forming consumption may relate not only intertemporally but also contemporaneously to other habit-forming consumptions.

The relaxation of the commodity-specificity certainly is not new. To explain the binge (i.e. “a cycle over time in the consumption of a good”), Becker and Murphy (1988, p. 693) introduce a second but satiating habit of a consumption, and show that the cyclical addictive behavior can be explained through a consistent utility maximization. Later, Dockner and Feichtinger (1993, p. 257) refine the explanation on the binge, and note the requirement of the dynamics behavior of binge; “two counterbalancing effects” of addiction and satiation. Dockner and Feichtinger (1993) are the first who relate the existence of multiple habits to the concept of the commodity-specificity.

In section 2.2, I develop a general model of multiple addictions without the

commodity-specificity. It derives the necessary conditions, and interprets the habit-formation effect as a part of full price paid for the consumption. The necessary conditions lead to the discussion on several issues in addiction literature; the ‘formal and observational equivalence’ of Spinnewyn (1981) and Philips and Spinnewyn (1982), multiple addictions of Palacios-Huerta (2003a), and the ‘gateway effect’ of Kandel (1975) and Pacula (1997). It exemplifies how my model differs from ones in previous studies and extends the theory of rational addiction.

Section 2.3 provides the general solution of multiple addictions. It characterizes how the derived solution extends and generalizes previous findings in the rational addiction literature. It is then followed by section 2.4 that exemplifies the general solution with addiction to two commodities. Addiction to a pair of commodities is the simplest form of multiple addictions, but is general enough to examine the interaction of contemporaneous and intertemporal relations among habit-forming consumptions. It shows that without the commodity-specificity, the concept of adjacent complementarity is extended hierarchically toward ‘gross adjacent complementarity’ and indicates how a rational individual responds to multiple addictions. Furthermore, it notes the implication of contemporaneous relation (in the Edgeworth-Pareto sense) among consumptions on the degree of addiction. In section 2.5, I explain the gateway hypotheses and how religious activity may hinder substance use, based on the implication of multiple addictions. Section 2.6 provides the concluding remark.

This paper does not provide a review on addiction literature. Excellent reviews on the economic study of addiction can be found in Messinis (1999), Chaloupka and Pacula (2000), and Chaloupka and Warner (2000); Elster (1999) and Elster and Skog (1999) for the psychology and behavioral study; and Peele (1985) and Koenig et al. (2001) for the non-economic disciplines. This paper appears to be the first which studies multiple addictions from the perspective from the non-commodity-specificity of habits and focuses on the interaction among the habit-formation effects. In doing so, this paper also highlights the importance of the contemporaneous relation on the addictive property of consumptions, and provides a theoretical ground in estimating the econometric model of multiple addictions.

2.2 The Model

I study multiple addictions by generalizing the model in Iannaccone (1986) and Becker and Murphy (1988). To so do, an individual is assumed to derive the utility from n -commodities that are habit-forming and there are same number of commodities and habits, $n = m$: $c \in \mathbb{R}^n$ and $S \in \mathbb{R}^n$. Furthermore, I assume that the accumulation of S_i depends on (c, S_i) and $f(c) = \alpha c$; that is, it follows

$$\dot{S} = \alpha c(t) - \delta S(t) \quad (2.6)$$

where α is a square matrix with α_{ii} and α_{ij} . α_{ii} and α_{ij} reflect the marginal product or the degree in which the consumptions of c_i and c_j affect the accumulation rate of S_i , respectively. Thus, a habit measures the δ_i -weighted average of past consumption profiles, while the past consumption profile is another α -weighted average. The determinant of $\alpha c(t)$ is assumed to be non-negative. I also assume that the rates of interest and time preference are same, $r = \rho$.

Other arguments in (2.1)-(2.4) remain same. The objective is, then, to achieve (2.1) subject to (2.3), (2.4), and (2.6). It is a dynamic maximization problem with an inequality integral constraint that requires a conversion of the wealth constraint into the equation of motion of a new state variable Γ for the wealth constraint (2.3), and $\dot{\Gamma}$ is derived in Appendix C.1 (Chiang, 1992). Introducing a costate variable vector $\lambda \in \mathbb{R}^n$ and a scalar costate variable μ , the current-valued Hamiltonian can be defined,

$$H \stackrel{\text{def}}{=} u(c, S) + \lambda(\alpha c - \delta S) + \mu(-pce^{-rt} + w(S)e^{-rt}). \quad (2.7)$$

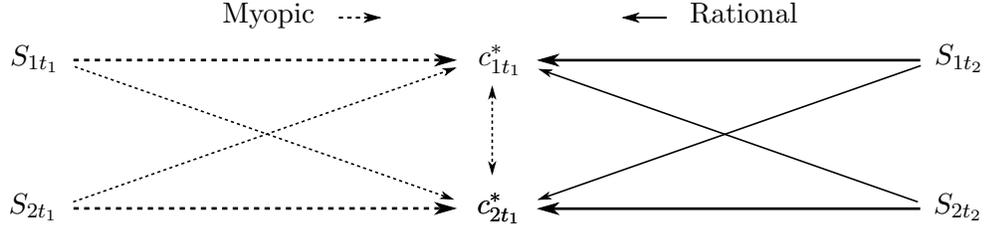


Figure 2.2: Interaction under Consideration

I note following necessary conditions.

$$H_c = u_c + \lambda\alpha - \mu\rho e^{-rt} = 0 \quad (2.8)$$

$$\dot{\lambda} = -H_S + \rho\lambda \quad (2.9)$$

$$\dot{\mu} - \rho\mu = -H_\Gamma = 0 \quad (2.10)$$

$$\lambda(T)e^{-\rho T} = 0, \Gamma(T) + A_0 \geq 0, \mu e^{-\rho T}(\Gamma(T) + A_0) = 0 \quad (2.11)$$

From the maximum principle, the solution satisfying (2.6) and necessary conditions is sufficient to guarantee the optimality of consumption path.

Assuming an individual consumes a pair of commodities that are habit-forming, (c_1, c_2) , figure 2.2 depicts the habit-formation effects of two habits that an individual considers in order to decide an optimal consumption bundle, $c^* = (c_1^*, c_2^*)$. With the commodity-specificity, only the habit-formation effect shown by the bold line is considered when deciding the consumption level of either c_1 or c_2 (the lines only in top or bottom), and it is what defines the degree of adjacent complementarity in Iannaccone (1986) and Becker and Murphy (1988). With the non-commodity-specificity, the rest of habit-formation effects in the thin lines are included. Figure 2.2 recognizes the difference between myopic and rational individuals as well. The dotted line shows the reinforcement of habit-formation effects (i.e., a positive experience effect) that a myopic individual considers, while a rational individual adds the possible adverse effects in the solid line into the consideration. It indicates that a rational individual is aware of the future consequence of current

consumption of c , which is a much more complex problem to solve.

A few remarks on the economic intuition can be made through necessary conditions. It may help understanding the implications of necessary conditions, if (2.8) is stated in an algebraic form. As shown in Appendix C.1, I can restate (2.8) as

$$u_{c_i} = -\Lambda_i + \mu p_i e^{-rt} \quad (2.8')$$

where

$$\Lambda_i = \alpha_{ii} \lambda_i + \sum_{j \neq i}^n \alpha_{ji} \lambda_j, \quad (2.12)$$

$$\lambda_k = \int_t^T e^{-(\rho+\delta_k)(\tau-t)} u_{S_k} d\tau + \int_t^T \mu e^{-(\rho+r+\delta_k)(\tau-t)} w_{S_k} d\tau, \quad (2.13)$$

and $k = i$ or j . The wedge λ_i is the future benefit or cost of habits being added from current consumption of c_i . It makes current and future instantaneous utilities interdependent, and shows the rationality of an individual. Two interpretations of the wedge are feasible: One may take the wedge as “the future utility [or disutility] generated by current consumption” (Iannaccone, 1986, p. 97); or it is also possible to take it as a part of the full price paid, “the money value of the future cost or benefit of consumption” (Becker and Murphy, 1988, p. 678).

That a same wedge has two interpretabilities is a strength of the rational habit-formation model. It accommodates the critics of a stable preference assumption, who view the change of choice over time is caused by an endogenous change of preferences. On the other hand, it seems to have contributed to the idea that myopic and rational models are also “observationally equivalent” - an “equivalence in terms of a regression model” (Phlips and Spinnewyn, 1982, pp. 23-4). As shown by Pashardes (1986, p. 387), however, the dynamic demand equations “with the myopic and rational specifications are not empirically equivalent except under certain restrictions on preferences [Cobb-Douglas to be more

precise].” In doing so, he also develops “a general model which has myopia and rationality as its two limiting cases,” a similar feature found in the theory of rational addiction and here through the rate of time preference.

On the other hand, Chaloupka (1991) and Chaloupka and Pacula (2000) step further and dismiss the basis of the observable equivalence, the “formal equivalence” of Spinnewyn (1981, p. 92) that the models with and without habit-formation are indistinguishable when the cost of consumption and wealth is reformulated to reflect the true cost of addiction, including the future consequences of current consumption of c . As shown by two interpretabilities of a same wedge, however, whether to include the wedge, the future consequences of current consumption of c , as a part of utility or wealth in the theory of rational addiction and here is a matter of a reader’s convenience.

Whether the formal equivalence may also lead to the observable equivalence is rather a technical issue, involving an assumption on an individual’s future cost consideration. For instance, the condition for an observational equivalence in Spinnewyn (1981, see eq. (5.1)) depends on a coefficient, called ω , that measures the difference between current-only and future-including prices, which also applies to Pashardes (1986, see eq. (10)) through an intuitively-same coefficient called λ . The derived regression models with myopia and rationality in the economic theory of addiction and here will have different specifications, in a sense that the rational demand for addictive commodities is an explicit function of future consumptions and prices. However, if the future effect is considered to be a part of current money price paid (i.e., the future consequences coming through a same gate as current-only monetary cost), “the estimated coefficients [of rational regression model] has another interpretation” than that of myopic counterpart (Spinnewyn, 1981, p. 108) where an equivalence of the regression models is observable.

I follow Becker and Murphy (1988)’s approach and set the full price

$$\pi_i = -\Lambda_i + \mu p_i e^{-rt}.$$

As the commodity-specificity converts α to a diagonal matrix only with α_{ii} , $\alpha_{ii}\lambda_i$ is a sole component in Λ_i when the habits are commodity-specific. As μ is a current-valued costate variable, it is easy to see that when $\alpha_{ii} = 1$, (2.8') resembles the first order condition of the habit-forming consumption in Becker and Murphy (1988, pp. 677-8) where λ_i is the shadow price of an additional stock of a habit.

That $\Lambda_i = \alpha_{ii}\lambda_i$ with the commodity-specificity also shows how the problem considered here differs from a recent work by Palacios-Huerta (2003a) on multiple addictions. In it, he considers multiple habit-forming consumptions while the commodity-specificity is still intact. He argue that it explains the cyclical consumption patterns without special conditions and also the episodic consumption of addictive commodities. As shown by the implication of the commodity-specificity on the full price, the dynamics that allows such consumption patterns in Palacios-Huerta (2003a) is more restrictive and different than mine. For example, the latter term in RHS of (2.12) is not a part of Λ_i in his analysis, and it cannot explain the multiple habit-formation effects on the future price of c_i .²

The wedge Λ_i let an individual internalize the future cost or benefit of current consumption of c_i into the domain of current decision-making through the habits being accumulated. Its sign shows whether the consumption of c_i has a positive or adverse effect on future utility or wage. With the commodity-specificity, whether its habit S_i is beneficial ($u_{S_i}, w_{S_i} > 0 \Rightarrow \lambda_i > 0$) or harmful ($u_{S_i}, w_{S_i} < 0 \Rightarrow \lambda_i < 0$) determines the characteristic of c_i . However, with multiple habit-forming consumptions, c_i is beneficial when $\Lambda_i > 0$, and is harmful when $\Lambda_i < 0$.

The size and sign of Λ_i clearly depends on the 'gross characteristic' of habits and α (i.e., the relative degree in which the accumulation of habits is affected by each consumption). If every consumption, c , has a same characteristic and future consumptions are held fixed, the absolute value of Λ_i is larger, suggesting a smaller consumption of a harmful c_i but a larger consumption of a beneficial c_i . Furthermore, if the degree in which consumption of c_i

²As I shall discuss later, the dynamic behavior Palacios-Huerta (2003a) discusses does not necessarily imply that an individual is rationally and multiply addicted, at least not in a sense that Iannaccone (1986) and Becker and Murphy (1988) conceptualize addiction (i.e., a positive relation between c and S).

affects the accumulation of S_j is relatively larger ($\alpha_{ji} > \alpha_{ij}$), consumption of c_i is smaller as the full price for consumption of c_i is relatively higher ($\pi_{c_i} > \pi_{c_j}$). It shows that depending on the relative contribution of consuming c to the accumulation of S , a particular order of the sequential development in substance use can be predicted. Also the standard result that “consumption of a harmful c is larger, and consumption a beneficial c is smaller, when δ and ρ are greater” also hold if c have same characteristic (Becker and Murphy, 1988, p. 678).

On the other hand, if the habits display different characteristics, the direction of change in consumption of c_i is ambiguous. But if consumption of c_i is harmful as $\Lambda_i < 0$, consumption of c_i and the level of tolerance are lower when any of its habits is beneficial. It implies that a rational individual who consumes harmful and beneficial c together is more satisfied with a given level of a harmful c_i than one who only consumes harmful c . As will be shown later, the implication on the level of tolerance when every c is harmful or it is the mixtures of harmful and beneficial consumptions is important in explaining the gateway effect and how religion and substance use relate.

2.3 General Solution

I wish to study multiple addictions by examining the intertemporal relation between past and current consumptions of c , where S measures past consumption of c . It is necessary to find the condition under which the habit-formation effects lead to addiction, and the linear approximation to the necessary conditions can characterize the dynamic behavior nearby the stationary point. As u_{cc} is negative definite and the consumption path of c is time-differentiable, I may differentiate (2.8) with respect to time,

$$\dot{c} = -u_{cc}^{-1}(u_{cS}\dot{S} + \alpha^{\text{tr}}\dot{\lambda}^{\text{tr}}), \quad (2.14)$$

which leads to the maximized Hamiltonian, $H^* = \max_c H$. As long as the transversality condition of Γ in (2.11) is met and μ is a nonnegative constant is kept in track, $\dot{\Gamma}$ and $\dot{\mu}$

may be omitted at no loss (Chiang, 1992, p.284).

The linear approximation to (2.6) and (2.9) yields the following system that describes the local stability property nearby the neighborhood of the stationary point,

$$\dot{x} = M(x^*)(x - x^*) \quad \text{where} \quad x = \begin{pmatrix} S \\ \lambda^{\text{tr}} \end{pmatrix}. \quad (2.15)$$

$M(x^*)$ is the Jacobian derivative of the $2n \times 2n$ matrix,

$$M(x^*) = \begin{pmatrix} H_{\lambda S}^* & H_{\lambda \lambda}^* \\ -H_{SS}^* & \rho I - H_{S\lambda}^* \end{pmatrix}. \quad (2.16)$$

The characteristic polynomial is of the $2n^{\text{th}}$ degree, and there are $2n$ characteristic roots. From Treadway (1971), I know that the roots are symmetric around $\rho/2$, implying $\rho - \beta_i$ also is a root if β_i is the root. Thus, the polynomial can be rather expressed in a quadratic form.

$$\begin{aligned} \det(M - \beta I) &= \beta^{2n} - C_1 \beta^{2n-1} + C_2 \beta^{2n-2} - \dots + C_{2n-2} \beta^2 - C_{2n-1} \beta + \det(J) \\ &= \prod_{i=1}^n \left(\left(\beta - \frac{\rho}{2} \right)^2 - \left(\beta_i - \frac{\rho}{2} \right)^2 \right) = 0 \end{aligned} \quad (2.17)$$

where C_n is the sum of all n^{th} order diagonal cofactors of M .

The optimal path of x is governed by

$$x = v e^{\beta t} + x^* \quad (2.18)$$

where v is a $2n \times 2n$ matrix and $e^{\beta t}$ is a $2n \times 1$ matrix with $e^{\beta_i t}$. v_i , the column of v (i.e.,

eigenvector of β_i), solves

$$Mv_i = \beta v_i. \quad (2.19)$$

where β is a diagonal matrix with β_i . As the real parts of β or $\text{Re}(\beta)$ are symmetric around $\rho/2$ and the transversality condition of λ in (2.11) implies $e^{-\rho T} \lambda(T) S(T) = 0$, any $\text{Re}(\beta) > \rho/2$ violates the transversality condition. Otherwise, the habits with positive values only in the lifetime will be left unused. If I let β_i^+ be the roots with $\text{Re}(\beta_i) > \rho/2$, β_i^+ can be ignored as the corresponding eigenvector for β_i^+ is forced to be zero, and the element in the either-half of v is zero.

As $\text{Re}(\beta_i^-) \leq \rho/2$, I can characterize the stability property of the system around the stationary point (S^*, λ^*) : The real roots are negative and the optimal path is monotonic and asymptotically stable; the complex roots have $\text{Re}(\beta_i^-) < 0$ and the optimal path is spiral and asymptotically stable; the complex roots have $\text{Re}(\beta_i^-) = 0$ and the optimal path is cyclical and neutrally stable; otherwise, the optimal path is unstable. Based on above stability property of the system (2.15), I can determine the optimal paths of S and, in consequence, relate them to the optimal consumption path.

If I let s and l be the upper and down quadrant of v , of which elements are not forced to be zero, respectively (i.e., s and l are the sub-matrices of v associated with S and λ), $e^{\bar{\beta}}$ be a $n \times 1$ matrix with $e^{\beta_i^- t}$, and $\bar{\beta}$ be a diagonal matrix with β_i^- , the roots corresponding non-zero eigenvector, I may rearrange (2.18)

$$S = se^{\bar{\beta}t} + S^* \quad \text{and} \quad \lambda^{\text{tr}} = le^{\bar{\beta}t} + \lambda^{*\text{tr}}. \quad (2.18')$$

Using (2.6), (2.14), (2.19), and (2.18') as derived in Appendix C.1, I have

$$\begin{aligned} \dot{c} &= \varphi \dot{S} \\ &= \alpha^{-1} (s \bar{\beta} s^{-1} + \delta) \dot{S} \end{aligned} \quad (2.20)$$

where s satisfies

$$(H_{SS}^* + (\rho I - H_{S\lambda})H_{\lambda\lambda}^{*-1})s\bar{\beta}^{-1} - (H_{\lambda\lambda}^{*-1}H_{\lambda S}^* + (\rho I - H_{S\lambda}^*)H_{\lambda\lambda}^{*-1})s + H_{\lambda\lambda}^{*-1}s\bar{\beta} = 0. \quad (2.21)$$

The sign of φ_{ij} , the element in φ , shows how consumption of c_i changes as S_j changes. When $\varphi_{ij} > 0$, consumption of c_i increases as S_j increases, and I call that consumption of c_i is addictive with respect to S_j .

φ is too abstract and complex to understand the economic meanings directly, and I postpone the discussion of them to the next section in which the simplest example of $n = m = 2$ is considered. However, it is still useful in showing how the theory of rational addiction is generalized and extended. By relating to the restriction imposed by the commodity-specificity, I may show that previous conditions of rational addiction are the special cases of (2.20).

1. *A Habitual Consumption and Commodity-Specificity:* With the commodity-specificity, α is diagonalized with $\alpha_{ii} \neq 0$ and $\alpha_{ij} = 0$, and the marginal rate of substitution between past and current consumptions of c_i only depends on itself. Then, how past consumption of c_i affects current consumption of c_i is independent of c_j . As how past consumption of c_j or S_j affects consumption of c_i is not relevant in deciding whether consumption of c_i is addictive, that the instantaneous utility is additive in pairs of (c_i, S_j) can be assumed without any loss of the generality in studying the addictive property of c_i . As the commodity-specificity and the additivity in utility diagonalize the matrices in (2.14) and the sub-matrices in M ($H_{\lambda\lambda}^*$, $H_{\lambda S}^*$, $H_{\lambda\lambda}^*$, $-H_{SS}^*$, and $\rho I - H_{S\lambda}^*$), addiction to consumption of c_i can be studied through the linearized system of (S_i, λ_i) and the 2×2 Jacobian derivative, also implying the equivalence of the approaches in Iannaccone (1986) and Becker and Murphy (1988). In consequence, s is a diagonal matrix with

$s_{ii} \neq 0$ and $s_{ij} = 0$, and (2.20) is reduced to

$$\dot{c}_i = \left(\frac{\beta_i + \delta_i}{\alpha_{ii}} \right) \dot{S}_i \quad (2.20.a)$$

where

$$\beta_i = \frac{\rho}{2} - \sqrt{\left(\frac{\rho}{2} + \delta_i \right)^2 - a_{ii}} \quad \text{and} \quad a_{ii} = \frac{-1}{u_{c_i c_i}} ((\rho + 2\delta_i)u_{c_i S_i} + \alpha_{ii}H_{S_i S_i}).$$

a_{ii} measures the degree of intertemporal complementarity of c_i to S_i . $\beta_i + \delta_i$ is positive if a_{ii} is positive or consumption of c_i is characterized by adjacent complementarity to S_i . It is straightforward that the results in Iannaccone (1986) and Becker and Murphy (1988) are when $\alpha_{ii} = f_{c_i}$ and $\alpha_{ii} = 1$, respectively.

2. *A Habitual Consumption and Non-Commodity-Specificity*: When $n = 1$ and $n \neq m$, αc is a $m \times 1$ matrix with $\alpha_{ji}c_i$, $u_{cc} = -u_{c_i c_i}$, and α is no longer invertible. With the non-commodity-specificity, it implies that how consumption of c_i relates to both S can be understood through solving a reduced (2.20) for φ and s . Then

$$\alpha \dot{c} = \alpha \varphi \dot{S} = (s\bar{\beta}s^{-1} + \delta)\dot{S} \quad (2.20.b)$$

where $\alpha \dot{c}$ is a $m \times 1$ matrix with $\alpha_{ji}\dot{c}_i$ and $\alpha \varphi$ is a $m \times m$ matrix with $\alpha_{ji}\varphi_{ij}$ and $\varphi_{ii} = \varphi_{ji}$.

To be clear about how a reduced (2.20) shown by (2.20.b) is a general solution of the finding about the binge in Becker and Murphy (1988) and Dockner and Feichtinger (1991, 1993), let me assume $\alpha_{ji} = 1$ and $m = 2$ so that M is a 4×4 matrix (i.e., $H_{\lambda\lambda}^*$, $H_{\lambda S}^*$, $H_{\lambda\lambda}^*$, $-H_{SS}^*$, and $\rho I - H_{S\lambda}^*$ are the 2×2 non-diagonal submatrices), $\alpha \dot{c} = (\dot{c}_i, \dot{c}_i)^{\text{tr}}$, and $\alpha \varphi = \varphi$. Then the unique solution for φ and s can be found through solving $\varphi s = s\bar{\beta} + \delta s$, and it

leads to

$$\begin{aligned}\dot{c}_i &= \varphi_{ii}\dot{S}_i + \varphi_{ij}\dot{S}_j \\ &= \frac{(\beta_i + \delta_i)(\beta_j + \delta_i)}{\delta_i - \delta_j}\dot{S}_i - \frac{(\beta_i + \delta_j)(\beta_j + \delta_j)}{\delta_i - \delta_j}\dot{S}_j.\end{aligned}\tag{2.20.b'}$$

where

$$\beta_{i,j} = \frac{\rho}{2} - \sqrt{\left(\frac{\rho}{2}\right)^2 - \frac{K}{2} \pm \frac{\sqrt{K^2 - 4 \det(J)}}{2}}$$

$$K = -\gamma_i - \gamma_j + a_{ii} + a_{ij}, \quad \det(J) = \gamma_i\gamma_j - \gamma_i a_{ij} - \gamma_j a_{ii}, \quad \gamma_k = \delta_k(\delta_k + \rho),$$

$$a_{ii} = \frac{-1}{u_{c_i c_i}} ((\rho + 2\delta_i)u_{c_i S_i} + H_{S_i S_i}), \quad a_{ij} = \frac{-1}{u_{c_i c_i}} ((\rho + 2\delta_j)u_{c_i S_j} + H_{S_j S_j}).$$

a_{ii} and a_{ij} measure the degree of intertemporal complementarity of c_i to S_i and S_j , respectively. If S_i is the habit with a higher depreciation rate such that $\delta_i > \delta_j$, φ_{ii} and φ_{ij} are positive when a_{ii} and a_{ij} are positive, implying that consumption of c_i is characterized by adjacent complementarity to S_i and S_j and that a rational individual is fully addicted. Yet, φ_{ii} is positive but φ_{ij} is negative when a_{ii} is positive and a_{ij} is negative, implying that consumption of c_i is characterized by adjacent complementarity to S_i but distant complementarity to S_j and that a rational individual is partially addicted. Same result is noted in Becker and Murphy (1988) and Dockner and Feichtinger (1991, 1993).

3. *Non-Additive Utility in Pairs*: The implication of the commodity-specificity also shows that multiple addictions Palacios-Huerta (2003a) refers to is different from multiple addiction defined through (2.20). As he assume the commodity-specificity, let me go back to the derivation of (2.20.a) but assume that the utility is no longer additive in pairs of (c_i, S_i) . Because of the commodity-specificity, α is a diagonal matrix and the marginal rate of substitution between past and current consumptions of c_i only depends

on itself: This implies that past consumption of c_j affects consumption of c_i , but it is not relevant in deciding whether consumption of c_i is addictive although the sub-matrices in M is not diagonalized as before. Thus, (2.20.a) will take the form of

$$\dot{c}_i = \left(\frac{\beta_i + \delta_i}{\alpha_{ii}} \right) \dot{S}_i + \sum_{j \neq i}^n \varphi_{ij} \dot{S}_j. \quad (2.20.a')$$

where S_{ij} do not include any information about past consumption of c_i . (2.20.a') suggests that the optimal path of c_i may be monotonic or cyclical, but consumption of c_i is not necessarily addictive in a sense that current consumption of c_i is raised by its past consumption. Furthermore, his numerical examples of monotonic and cyclical path are drawn when $u_{c_i S_i} = 0$ or < 0 (i.e., commodities has either no experience or negative experience effect), but argues that “the result in Dockner and Feichtinger (1993) [about monotonic path with the commodity-specificity] depends on not having any non-addictive commodities” (i.e., $n > m$) (Palacios-Huerta, 2003a, p. 14). It implies that he defines addiction when commodities are simply habit-forming.

Thus, the relation between c and S suggested by (2.20) generalizes and extends earlier findings about the condition of rational addiction. Moreover, multiple addictions suggested by it is different from Palacios-Huerta (2003a)'s.

2.4 Examples

To be explicit about the economic meaning of φ in (2.20), the simplest case of multiple addictions that $n = m = 2$ is employed. In addition, I assume the ‘quasi-commodity-specificity’ of habits. I call habits ‘quasi-commodity-specific’ when

1. The elements in α is related such that $\alpha_{ii} \geq \alpha_{ij}$.
2. The marginal rate of substitution of c for S depends on (c, S_i) . But how the marginal rate of substitution of c_i for S_i is affected by consumption of c_i is larger than that of c_j

for S_i is by consumption of c_j .

The first implies that S_i measures the δ_i -weighted average of past consumption profiles in which a more weight is given to c_i in the past consumption profile. The second implies that the degree in which the intertemporal reallocation of consumptions in c_i is affected by S_i is larger than the intertemporal reallocation in c_j , that the cross effect among stocks is zero, and that $\text{sgn}(\lambda_i) = \text{sgn}(\Lambda_i)$. The quasi-commodity-specificity is to explore the interaction among consumptions and its impact on the condition of rational addiction, while the absolute relation between a consumption and its primary habit is preserved. In other words, it leaves a clear sight on the forest (the primary effect) as well as dealing with the tree (the secondary effect).

Then, it is straightforward that $x = (S_1, S_2, \lambda_1, \lambda_2)^{\text{tr}}$ and M is a 4×4 matrix (i.e., $H_{\lambda\lambda}^*$, $H_{\lambda S}^*$, $H_{\lambda\lambda}^*$, $-H_{SS}^*$, and $\rho I - H_{S\lambda}^*$ are the 2×2 non-diagonal matrices). Based on the derivation for general solution and in Appendix C.1, it is clear that the characteristic polynomial is of the 4th degree

$$\det(J - \beta I) = \beta^4 - C_1\beta^3 + C_2\beta^2 - C_3\beta + \det(J) \quad (2.17')$$

and C_n is the sum of all n^{th} order diagonal cofactors of M . Four characteristic roots of M are

$$\beta_{1,2,3,4} = \frac{\rho}{2} \pm \sqrt{\left(\frac{\rho}{2}\right)^2 - \frac{K}{2} \pm \frac{\sqrt{K^2 - 4\det(J)}}{2}} \quad (2.22)$$

where $K = C_2 - \rho^2$.

Given the explicit characterization of the roots (2.22), it is nontrivial that the real parts of β or $\text{Re}(\beta)$ are symmetric around $\rho/2$. If I let $\beta_{3,4}$ be the roots with $\text{Re}(\beta_{3,4}) > \rho/2$, $\beta_{3,4}$ can be ignored as they violate the transversality condition, $\lambda(T)e^{-\rho T} = 0$. Moreover, following Dockner and Feichtinger (1991) who provide a lemma of the conditions that characterizes the stability property of the system with four eigenvalues, and using the

elements under the radicals in $\beta_{1,2}$, I can explicitly characterize the stability property around the stationary point.

1. The real roots are negative when $K < 0$ and $0 < \det J \leq \left(\frac{K}{2}\right)^2$, and the optimal path is monotonic and asymptotically stable.
2. The complex roots have $\text{Re}(\beta_{1,2}) < 0$ when $\det J > \left(\frac{K}{2}\right)^2$ and $\det J - \left(\frac{K}{2}\right)^2 - \rho^2 \frac{K}{2} > 0$, and the optimal path is spiral and asymptotically stable.
3. The complex roots have $\text{Re}(\beta_{1,2}) = 0$ when $\det J > \left(\frac{K}{2}\right)^2$ and $\det J - \left(\frac{K}{2}\right)^2 - \rho^2 \frac{K}{2} = 0$, and the optimal path is cyclical and neutrally stable.
4. Otherwise, the optimal path is unstable.

Based on above stability property of the system (2.15), I can determine the optimal paths of S and, in consequence, relate them to the optimal consumption path.

2.4.1 Myopic Multiple Addictions

At this moment, I step back little and study multiple addictions with the myopic habit-formation. The analysis with myopia provides a simplified way to understand multiple addictions. Its implications are only from the habit-formation effect from past consumptions on current one but without any consideration on the future consequence of current consumption through its habits being generated. Thus, it enhances the readability of a more complex dynamics with the rationality in a later discussion.

For myopic multiple addictions, I assume that an individual at a moment assumes that the habits are constant over time, $\dot{S} = 0$.³ In this case, an individual does not consider the wedge in (2.8) and takes the money price as the full price of c in the optimal planning. To prevent the possibility of exhausting the wealth too early, I assume that the lifetime wealth

³An individual is often called myopic when multiple selves over time are in conflict. See, for example, Winston (1980), Gruber and Köszegi (2001), and O'Donoghue and Rabin (2002) who study addiction as a consequence of the inconsistent time-discounting myopia, or self-control problem. An individual may also discount the future more heavily as the degree of addiction increases, where the rate of time preference is an endogenously-determined outcome (Becker and Mulligan, 1997; Orphanides and Zervos, 1998).

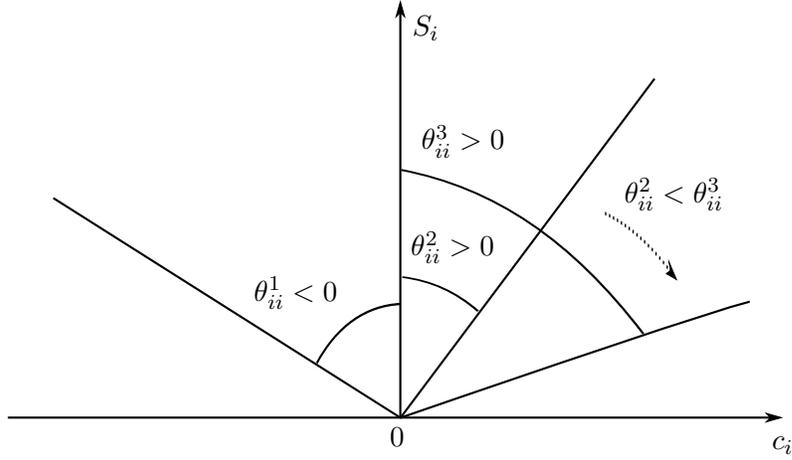


Figure 2.3: Myopic Addiction and Satiation in Relation of c_i and S_i

is ‘decentralized’ to each t , a feature usually found in other studies of myopic addictions such as Philips and Spinnewyn (1982). Then as $\dot{\lambda} = 0$, it implies the relation between c and S is governed by a simplified (2.14) of $\dot{c} = -u_{cc}^{-1}u_{cS}\dot{S}$. Solving it for c_i leads to

$$\dot{c}_i = \frac{\theta_{ii}}{|u_{cc}|}\dot{S}_i + \frac{\theta_{ij}}{|u_{cc}|}\dot{S}_j \quad (2.23)$$

where

$$\theta_{ii} = \begin{vmatrix} u_{c_i c_j} & u_{c_j c_j} \\ u_{c_i S_i} & u_{c_j S_i} \end{vmatrix}, \quad \theta_{ij} = \begin{vmatrix} u_{c_i c_j} & u_{c_j c_j} \\ u_{c_i S_j} & u_{c_j S_j} \end{vmatrix},$$

$$\text{and } |u_{cc}| = \begin{vmatrix} u_{c_i c_i} & u_{c_i c_j} \\ u_{c_i c_j} & u_{c_j c_j} \end{vmatrix} > 0 \text{ from the concavity of } u \text{ in } c.$$

In general, consumption of c_i is called addictive when consumption of c_i increases as its habits, S_i and/or S_j , increase.

Figure 2.3 shows how the sign and size of θ_{ii} determine the degree of myopic addiction or satiation through the relation between c_i and S_i . When $\theta_{ii}^1 < 0$, consumption of c_i decreases as S_i increases - consumption of c_i is satiating. When $\theta_{ii}^2 > 0$, consumption of c_i increases

as S_i increases - consumption of c_i is addictive. Moreover, consumption of c_i becomes more addictive when a positive θ_{ii} increases, $\theta_{ii}^2 \rightarrow \theta_{ii}^3$. Adopting the definition of full and partial addiction in Dockner and Feichtinger (1993) that an individual is ‘fully addicted’ when consumption of c_i is positively related to both stocks but is ‘partially addicted’ when only positively related to a stock, consumption of c_i is fully and myopically addictive when $\text{sgn}(\theta_{ii}) = \text{sgn}(\theta_{ij}) > 0$, and is partially and myopically addictive when $\text{sgn}(\theta_{ii}) \neq \text{sgn}(\theta_{ij})$.

I wish to interpret θ_{ii} and θ_{ij} economically. Iannaccone (1986, p. 97), for example, claims, but does not prove, that a myopic individual becomes an addict as “a commodity generate habits which raise the marginal utility of its consumption relative to other commodities.” The economic interpretation of θ_{ii} and θ_{ij} provides an opportunity to clarify his claim and shows how the contemporaneous relation among c affects the intertemporal one between past and current consumptions of c , or myopic addiction.

By letting $\kappa = (\kappa_1, \kappa_2) = (u_{c_1 c_2} / u_{c_2 c_2}, u_{c_1 c_2} / u_{c_1 c_1})$ and rearranging the elements of θ_{ii} and θ_{ij} , it is clear that

$$\theta_{ii} > 0 \text{ when } u_{c_i S_i} > \kappa_i u_{c_j S_i} \quad \text{and} \quad \theta_{ij} > 0 \text{ when } u_{c_i S_j} > \kappa_i u_{c_j S_j}. \quad (2.24)$$

where the sign of κ depends on the Edgeworth-Pareto complementarity - $\text{sgn}(\kappa) < 0$ when complements, $\text{sgn}(\kappa) = 0$ when independent, and $\text{sgn}(\kappa) > 0$ when substitute. (2.24) implies that consumption of c_i is ‘myopically addictive’ to S_i and S_j , respectively. For the rest of the paper, I assume that the diminishing marginal utilities of each consumption are larger than consumptions are complements or substitutes to each other. It implies that the size of κ is restricted such that $\kappa = \{-1 \leq \kappa_i \leq 1\}$.⁴

The condition for myopic addiction in (2.24) confirms Iannaccone (1986)’s claim. It suggests that a myopic individual is at least partially addicted either when a raise in the marginal utility of c_i induced by a habit, S_i , is relatively larger than a ‘ κ_i -adjusted’ raise

⁴One may argue that the Edgeworth-Pareto complementarity is not a proper indicator to define the relation among c . However, as Samuelson (1974) note, “E[dgeworth]-P[areto] are not so bad . . . it makes commodity sense to say, lobster is more subject to diminishing marginal utility than bread, or lemon is more a complement to tea than coffee is.”

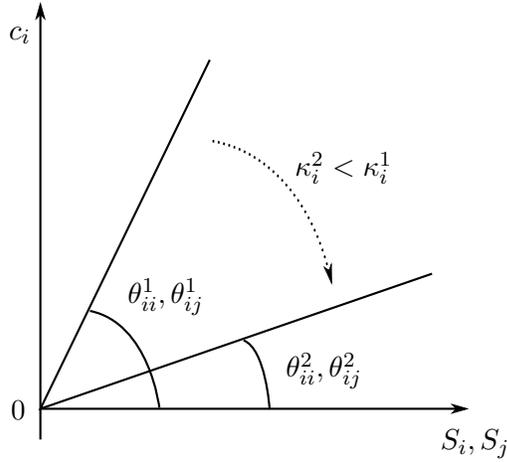


Figure 2.4: Myopic Addiction and Contemporaneous Relation

in c_j 's or when a reduction of it is relatively smaller. Furthermore, if the consumptions of commodities that are habit-forming are independent, a myopic individual is addicted to c_i when $u_{c_i S_i} > 0$ and/or $u_{c_i S_j} > 0$, which is the definition of myopic addiction when the habits are commodity-specific and provided by Iannaccone (1986). Indeed, if the commodity-specificity is assumed, the contemporaneous relation among commodities that are habit-forming has no role in deciding the condition of myopic addiction.

To discuss the implication of the contemporaneous relation among c on myopic addiction, let me assume that the marginal utilities of c_i are raised by both stocks, $u_{c_i S} > 0$.⁵ The RHS of (2.24) is largest when $\kappa_i = 1$ and is smallest when $\kappa_i = -1$. In other words, as commodities that are habit-forming, c , become less complements and approach to be more substitutes $\kappa_i \rightarrow 1$, θ_{ii} and θ_{ij} are smaller. It suggests that the degree of which a myopic individual is addicted to c_i is smaller as commodities that are habit-forming, c , are more of substitutes. Moreover, a myopic individual may eventually become fully or partially satiated to c_i if $\kappa_i u_{c_i S_j}$ exceeds $u_{c_i S_i}$ and/or $\kappa_i u_{c_j S_j}$ exceeds $u_{c_i S_j}$. Figure 2.4 displays the effect of the contemporaneous relation or κ_i on myopic addiction with respect to c_i .

I am also interested in multiple addictions, where a myopic individual is addicted to multiple commodities that are habit-forming. An individual is 'multiply addicted' when

⁵Analysis can be easily extended through various combinations of the signs in $u_{c_i S} = (+/-, +/-)$.

both habit-forming commodities, c , are at least partially addictive, or if $\text{sgn}(\theta_{11}) \neq \text{sgn}(\theta_{12})$ and $\text{sgn}(\theta_{21}) \neq \text{sgn}(\theta_{22})$. A myopic individual is fully addicted to both commodities that are habit-forming, c , if $\theta_{11}, \theta_{12}, \theta_{21}, \theta_{22} > 0$.

To consider the implication of the contemporaneous relation among commodities that are habit-forming, c , on myopic multiple addictions, let me assume that a myopic individual is fully addicted to both commodities, c . Combining the respective inequality conditions of the coefficients θ and rearranging them lead to

$$(1 - \kappa_j)u_{c_i S_i} > (\kappa_i - 1)u_{c_j S_i}, \quad (2.25)$$

which defines the condition for full myopic addiction to both commodities, c , with respect to a habit, S_i . It suggests that the bandwidth for full multiple addictions of a myopic individual narrows as commodities that are habit-forming, c , approach to be closer substitutes and that a myopic individual at most can be only partially addicted to both commodities, c , if they are perfect substitutes, $\kappa = (1, 1)$.

In providing the definition of full and myopic addiction, Dockner and Feichtinger (1993, pp. 259-60) note “*partially addicted*... behavior most likely results in consumption cycles” and claim “[o]nly a consumer... who anticipates the future consequences of his current actions can end up in... cycles.” Given a high probability of partial addiction when a myopic individual is addicted to multiple substitutes, it is not clear how and why a myopic individual cannot display the cyclical consumption pattern. Counterbalancing multiple habit-formation effects on current consumption of c_i , along with the fluctuation in the instantaneous ratios of the accumulated stock levels, may as well result in consumption cycles even for a myopic individual.

The contemporaneous relation among c clearly affects myopic multiple addictions. The remaining task is to see whether the insight on a myopia individual carry over to a rational individual.

2.4.2 Rational Multiple Addictions

Rational addiction, like myopic counterpart, is also defined through the relation between c and S . Similar to how consumption of c_i is related to both S for a myopic individual and as shown in Appendix C.1, consumption of c_i can be directly related to both S .

$$\begin{aligned} \dot{c}_i &= \varphi_{ii}\dot{S}_i + \varphi_{ij}\dot{S}_j \\ &= \frac{(\beta_i + \delta_i)(\beta_j + \delta_i)}{(\alpha_{ii} + \alpha_{ij})(\delta_i - \delta_j)}\dot{S}_i - \frac{(\beta_i + \delta_j)(\beta_j + \delta_j)}{(\alpha_{ji} + \alpha_{jj})(\delta_i - \delta_j)}\dot{S}_j. \end{aligned} \quad (2.20')$$

It is clear that c_i increases when S_i and S_j increase if $\varphi_{ii}, \varphi_{ij} > 0$. The task is to understand the economic meaning of what makes either coefficient, φ_{ii} or φ_{ij} , positive and see if the intuition for a myopic individual carries over to multiple addictions with the full rationality.

(2.20') indicates that how consumption of c_i relates to both habits, S , depends on the multiplication of sums of roots and discount rates. Assuming S_i is the habit with a higher discount rate, φ_{ii} is positive when $\text{sgn}(\beta_i + \delta_i) = \text{sgn}(\beta_j + \delta_i)$ and φ_{ij} is positive when $\text{sgn}(\beta_i + \delta_i) \neq \text{sgn}(\beta_j + \delta_j)$. Similar to an earlier discussion on myopic addiction, I arrive at the condition of rational addiction by looking at the elements of the roots and how they decide the sign of the sum of roots and discount rates. As shown in Appendix C.1,

$$\varphi_{ii} > 0 \text{ when } \alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0 \quad \text{and} \quad \varphi_{ij} > 0 \text{ when } \alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0 \quad (2.26)$$

where

$$A_{ii} = \frac{1}{|u_{cc}|} ((2\delta_i + \rho)\theta_{ii} + H_{S_i S_i} \chi_{ii}), \quad A_{ij} = \frac{1}{|u_{cc}|} ((2\delta_j + \rho)\theta_{ij} + H_{S_j S_j} \chi_{ij}),$$

and

$$A_{ii} > 0 \quad \text{when} \quad (2\delta_i + r)u_{c_i S_i} + \alpha_{ii}H_{S_i S_i} > \kappa_i ((2\delta_i + r)u_{c_j S_i} + \alpha_{ij}H_{S_i S_i}). \quad (2.27)$$

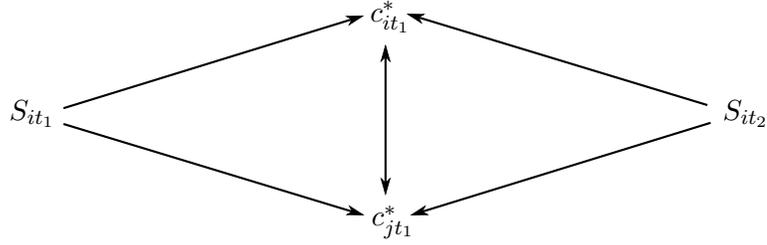


Figure 2.5: Rational Addiction and Gross Adjacent Complementarity of c_i to S_i

(2.27) implies that A_{ii} measures the degree of adjacent complementarity of c_i to S_i , which is the sum of adjacent complementarities with the commodity-specificity of c_i to S_i and of c_j to S_i (a_{ii} and a_{ji} in section 2.3), rather than of c_i to S_i alone. Another way to interpret A_{ii} is to understand it as adjacent complementarity from how c_i relates to the portion of S_i that are only accumulated by past consumption of c_i . For example, if S_i measures only past consumption of c_i as $\kappa_i = 0$, RHS of (2.27) would be zero, and leads to the equivalent condition of adjacent complementarity in Iannaccone (1986) and Becker and Murphy (1988) (i.e., a_{ii} in (2.20.a)). Assuming $a_{ii}, a_{ji} > 0$, a_{ji} reduces or enhances A_{ii} depending on whether c are substitutes ($\kappa_i > 0$) or complements ($\kappa_i < 0$).

Moreover, (2.26) implies that consumption of c_i is addictive to S_i when $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$ and is addictive to S_j when $\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$. Thus, with the non-commodity-specificity, the concept of adjacent complementarity is extended as the α -weighted average of sums of adjacent complementarities with the commodity-specificity. This triggers me to introduce a new term. In particular, when $n = m = 2$, I call that an individual is under ‘gross adjacent complementarity’ with respect to c_i when $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$ and/or $\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$. Essentially gross adjacent complementarity is an extended form of adjacent complementarity with the commodity-specificity, and can be easily reduced to an equivalent form in (2.20.a), a_{ii} .

Figure 2.5, a sub-map of figure 2.2, visualizes gross adjacent complementarity. As the direction of arrows indicates, it shows that gross adjacent complementarity of c_i to S_i not only depends on adjacent complementarity of c_i to S_i (the upper-half of figure 2.5) but also that of c_j to S_i (the lower-half). Indeed, gross adjacent complementarity is

defined as the α -weighted average of sums of two adjacent complementarity to S_i with commodity-specificity.

I may also discuss the effect of the contemporaneous relation among c on rational addiction with the non-commodity-specificity. Similar to the analysis on myopic addiction, let me assume that c_i is characterized by particular adjacent complementarity to both S (i.e., $A_{ii}, A_{ji} > 0$). (2.26) and (2.27) with the intuition on the sign of the coefficient imply that gross adjacent complementarity is smaller when substitutes and is larger when complements - c_i is rationally more addictive with respect to S_i as c are closer substitutes. Thus, the intuition on myopic addiction of the contemporaneous relation also applies to rational addiction. Furthermore, as the stability property states that for complex roots to exist

$$K^2 - 4 \det(J) = ((\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji}) + (\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj}))^2 + 2(\gamma_i - \gamma_j)((\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj}) - (\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji})) + (\gamma_i - \gamma_j)^2 < 0,$$

any cyclical consumption pattern requires partial addiction, and the magnitude of the consumption cycle is greater as the gap in the degrees of addiction to S_i and satiation to S_j is greater. Then, since c_i is relatively less addictive to S_i and less satiating to S_j as c are closer substitutes, it also implies that the consumption cycle is with a less magnitude. In other words, the consumption of two closer substitutes that share habits results in a lesser degree of addiction and a smoother optimal policy. On the other hand, it also predicts that a rational individual who is multiply addicted to complements is likely to display a more severe binge-like behavior.

2.5 Discussion

I have so far discussed the implication of the non-commodity-specificity to the theory of rational addiction and how the contemporaneous relation may alter the addictive degree

of habitual consumptions. Moreover, the concept of adjacent complementarity is extended hierarchically to gross adjacent complementarity. There are two particular hypotheses that await for further economic explanation, in which previous analysis is useful.

2.5.1 Gateway Hypotheses

Based on the theory of rational addiction, Pacula (1997) provides an economic model of the gateway effect where various substances accumulates a general habit. Furthermore, she argues that the sequential development of “drug use can be explained by differences in the marginal cost of consuming particular drugs” and “public policy may be effective at reducing the demand for illicit substances by raising the marginal cost of initiation drug” (Pacula, 1997, pp. 523-4).

As briefly discussed in section 2.2, the first order condition (2.8) confirms her first claim that it may become cheaper to use the substance in a higher order if its gateway drug is already consumed. Yet, the analysis also suggests that it happens only when the gateway drug and the substance in a higher order are substitutes. Thus, it suggests that the existence of the sequential development in substance use depends on a particular contemporaneous relation among substances, and shows that a licit drug may only have the gateway effect on some illicit drugs but not on all. For example,

The analysis also shows that the raise in the marginal cost of gateway drug may deter the non-users of the gateway drug from becoming its addicts, and lower the chance of being exposed to substances in a higher order. However, it also predicts that the existing addicts of the gateway drug will instead start using drugs in higher orders as it is now relatively cheaper to do so. For example, the tax policy that raises the price of cigarette may prevent the initiation of smoking cigarette among non-smokers and the exposition to marijuana. On the other hand, it can be predicted that the number of the migrants from cigarette to marijuana increases as the relative price of marijuana is cheaper. Thus, the tax policy on the gateway drug has two opposing effects; the deterrent effect among the non-addicts and the migrant effect among the addicts.

Another implication that relates to the gateway effect is on the severeness of binge in addictive consumptions. The model of multiple addictions suggests that when two addictive consumptions are complements, the chance of a severe binge is more likely, where the magnitude of binge is larger. For example, consider cigarette and alcohol that are found to be complements. A larger magnitude with closer complements of addictive consumptions implies that a light smoker of cigarette when not drinking may become a chain smoker while drinking alcohol.

2.5.2 Religion and Substance Use

In sociology and medicine of religion, how religion may prevent substance use is explained around the “hellfire hypotheses” that as people believe in punishments in hell for wrongdoings while on earth, they are deterred from delinquency including substance use (Hirschi and Stark, 1969). Later on, the hellfire hypotheses is refined by the “reference group hypotheses” that the more proscriptive a religious group is the more likely its member abstains from substance use (Cochran and Akers, 1989) and the “moral community hypotheses” that the deterrent effect of religion requires the support of the community and becomes only significant when it is ratified by the social environment (Stark, 1996). The economic argument of the hellfire hypotheses is similar to the “salvation motive” of Azzi and Ehrenberg (1975) that a household rationally devotes their time and effort in religious activities for the expected afterlife consumption; that is, the expected afterlife benefit or reward is the factor that influences the choice of a household among secular and religious activities, and an individual may avoid substance use in the fear of afterlife punishment.

The insight of multiple addictions suggests that religion may hinder substance use without the consideration of the benefit or punishment in the afterlife, but confirms the later refinement of the hellfire hypotheses. The analysis on multiple addictions indicates that religion may deter substance use through two effects: The first is reducing the degree of gross adjacent complementarity to substance by dissipating the habit-formation effect of substance by the religious participation, and the second is the satiating effect of gross

distant complementarity to substance by the religiosity accumulated by the participation in religion. Thus, by participating in religion, the substance addicts may suffer less from the tolerance as the religious participation directly dissipates the habit associated with substance use

2.6 Conclusion

In this paper, I consider a seemingly simple extension of the theory of rational addiction, where habits are not commodity-specific. A habit is called commodity-specific when (1) a habit is accumulated by a specific consumption and (2) the marginal rate of substitution of a consumption for a habit depends only on a particular pair of consumption and habit. By allowing the non-commodity-specificity, I study multiple addictions and find that contemporaneous relation (in the Edgeworth-Pareto sense) among addictive consumptions alters the addictive degree of them. The condition of rational addiction with the non-commodity-specificity shows that as the considered number of habitual consumptions increases, the concept of adjacent complementarity extends hierarchically to what I call ‘gross adjacent complementarity.’ I also find that the gateway effect exists when addictive consumptions are substitutes and that the increase in the price of the gateway drug has the deterrent and migrant effects, ascribable to the income and substitution effects.

Chapter 3: Religion and Substance Use

“And take heed to yourselves, lest at any time your hearts be overcharged with surfeiting, and drunkenness, and cares of this life, and so that day come upon you unawares.”

Luke 21:34. Bible, James King Version

3.1 Introduction

Despite of many predictions based upon the secularization theory that religion is “doomed to disappear in an era of science and general enlightenment” (Lenski, 1963), there is a clear sign that religion remains as a significant part of American’s life. For instance, Hadden (1987), by using the Gallop’s annual Religion in America report for 1985, reports that church membership and church attendance in America have been stable since 1940s, and Stark and Bainbridge (1985) argue that two counterbalancing forces of religion – “revival” and “religious innovation” – will enable “the amount of religion” in societies to “remain relatively constant.” Thus, it is not surprising to see that economists recently have recognized the importance of religion and have begun to study behavioral and organizational properties of religion.

Unlike economists’ lag in studying religion, their counterparts in sociology have continuously produced research programs that are exclusively devoted onto studying various aspects of religion at individual, social, and cultural level.¹ However, sociology of religion, while abundant in documenting empirical patterns in religions, lacks the theory, and much progress of understanding religion awaits the combined effort of economic theory and sociology data (Iannaccone, 1998). One such area is the religious effect on substance use

¹The first work on religion by economist since Adam Smith’s Wealth of Nations appeared in 1975, being 2 centuries apart.

or abuse. While the empirical literature examining the link between two has produced more than 200 papers in sociology, psychology, and medicine, why two may actually link each other relies on only three theoretical frameworks – hellfire, reference group, and moral community hypotheses.

In this paper, I attempt to link the framework identified in earlier chapters to the literature that finds a negative association between religion and substance use. In economics, both religion and substance use are regarded to be the consumption of addictive commodities. Only difference is whether they are beneficial or harmful, respectively (Becker, 1992; Becker and Murphy, 1988).² In other words, religion and substance use are types of the increased consumption behavior that is induced by past experience even with the rise in future price paid. An individual may strategically consume religion as it helps to unhook oneself from addiction to substance.

I borrow the intuition developed in previous chapters that when the consumption of two commodities influences a same consumption capital, two commodities (i.e., religion and substance use) are linked dynamically.³ There may be three effects of religion on substance use as religious practice accelerates the depreciation of habits formed by substance use: First, as the consumption capital from substance use is dissipated by religious practice, current substance use is much less enforced from past use. Second, as the satisfaction gap between a given level of substance use in past and today becomes narrower, higher level of past substance use leads to much less loss in the utility from current substance use. And third, the reduction or interruption in current substance use does not result in the reduction in utility. As the increase in religious practice causes three effects, an individual chooses to reduce substance use.⁴

²A person is considered to be rationally addicted if one considers the past as well as the future consequences for current consumption decision. For more discussion on the economic definition of addiction, please see Becker et al. (1991); Iannaccone (1986).

³Readers should note the difference in our treatment for non-commodity-specific consumption capital. When the assumption of commodity-specific consumption capital is relaxed, it automatically leads to the consumption of a commodity being responsible for the accumulation of two capitals. However, we pinpoint the key feature of non-commodity-specific consumption capital to be a capital being accumulated and/or dissipated by the consumption of different commodities.

⁴The direction of causality may also be in a reversal order. We expect same effects will take place on religious practice when an individual increases substance use, indicating the bi-causality between religion

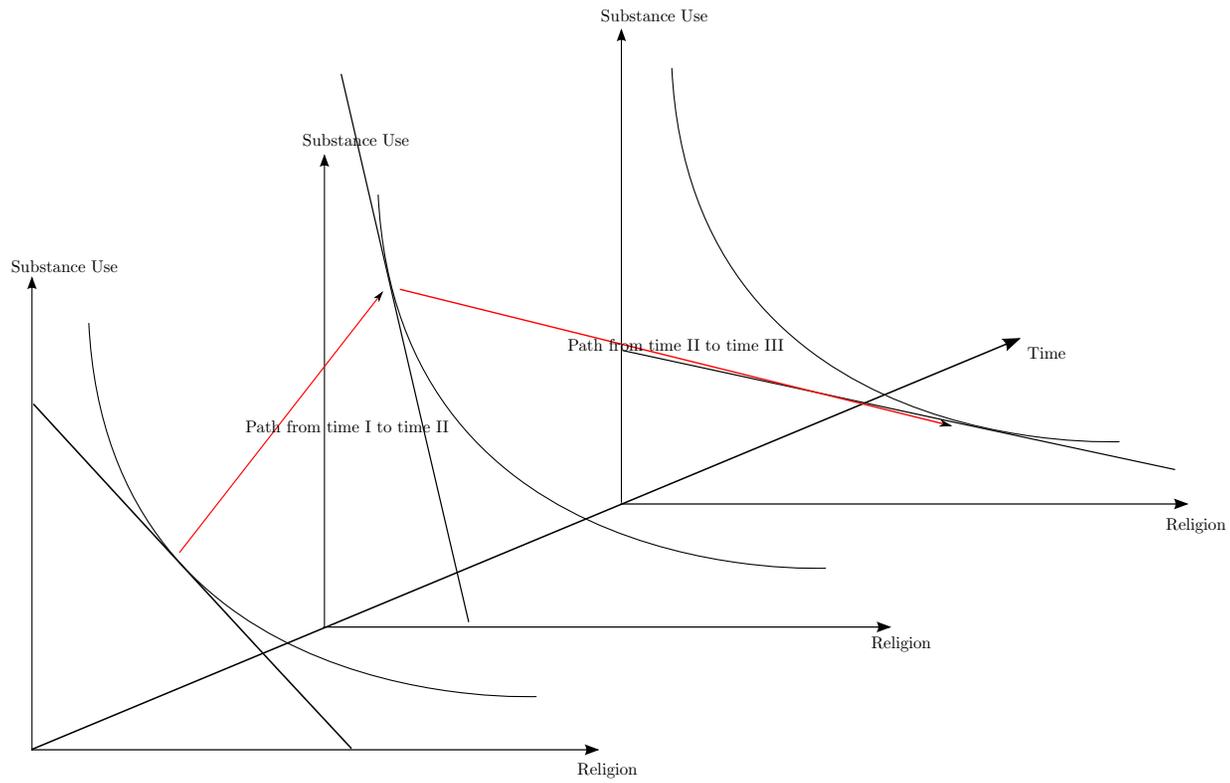


Figure 3.1: Interaction of Religion and Substance Use

These effects are closely related to three hypotheses that are used in the empirical testing concerning the link between religion and substance use. Moreover, they imply the reduction of three features of addiction noted in psychology literature; reinforcement, tolerance, and withdrawal. In figure 3.1, I graph how three effects alters the relative price structure as the habit from consuming substance is dissipated by religious activities. In time I to II, as an individual accumulates the stock of habit from consuming substance, it becomes relatively cheaper to consume and an individual is induced to consume more of it. However, in time II to III, as an individual strategically engages in religious activities, it dissipates the stock of habit and begins changing the relatively price structure inversely. Thus, an individual may overcome addictive nature of substance.

The paper proceeds in following manner: In section 3.2, we review the empirical literature on religion and substance use based on three benchmarks for data analysis: hellfire, reference group, and moral community hypotheses. The literature review brings our attention to a stylized fact of the negative association between religion and substance use. In section 3.3, I enumerate various empirical works that confirm the stylized fact. I note their main hypothesis, findings, and data source. It provides the overall view on the hypothesis that have been empirically tests and where their data came from. In section 3.4 concludes the paper.

The contribution of this paper is twofold. First, this paper is the first attempt to systemically link the ration-addiction model to the relationship between religion and substance use. The framework in previous chapters shows how and why quiet seemingly-unrelated behaviors are related and influence each other. It provides a rationale for the motive to participate in religion. A person may participate in religion for potential benefit in one's afterlife. However, we often observe people going to the church solely on for the side benefit – making friends, family tradition, life-discipline, etc. Harmful addiction may be another reason to participate in religion. If addicts want to unhook from harmful habits such as cigarette smoking, alcohol drinking, and drug usage and know having the

and substance use.

religion helps, then they may strategically consume religion. Second, this paper reviews a large empirical literature on religious effect on substance use in sociology, psychology, and medicine. By providing the hypothesis tested and the date used, it helps future researchers to have an easy access and understanding to the multidisciplinary on the relationship between religion and substance use.

3.2 Literature Review

This section provides the overview of previous findings on religion and substance use. In the literature of sociology and medicine of religion, whether religion and substance use is negatively related or have any association is statistically tested mainly based upon three hypotheses – hellfire, reference group, and moral community hypotheses.⁵ Empirical support for each hypothesis somewhat differs. However, there seems to be a consensus converging onto a stylized fact, the negative association between religion and substance use.

3.2.1 Hellfire Hypothesis

The systemic examination of religion and substance use begins with the paper by Hirschi and Stark (1969) that disputes the existence of the relationship between religion and delinquency. Although substance use is not a part of delinquency they examined, one of their postulated links between religion and delinquency that fails to be confirmed has provided the framework that has led many subsequent works on religion and substance use (Bock et al., 1987; Chadwick and Top, 1993; Cochran and Akers, 1989; Stark, 1996). The hellfire hypothesis they suggested is that, as people believe in punishments in hell for wrongdoings while on earth, they are deterred from delinquency including substance use.⁶

⁵For more complete review of literature, please see Chadwick and Top (1993); Cochran and Akers (1989); Koenig et al. (2001); Miller (1998).

⁶Recently Harris (2003) postulated that the belief in “earthly rewards and punishments” from God may be more important and significant deterrent effect of religion on substance use. Using adolescent data from the Mormon Church that promotes the idea of this-worldly sanction by God, he argued that the belief in earthly sanction has a relatively larger deterrent effect on future substance use than one in the hellfire. However, his argument rests on same logic that the belief in sanction deters delinquent behaviors. Only

Ironically the hellfire hypothesis, we believe, can be explained most clearly by the ‘salvation motive’ identified by the model in Azzi and Ehrenberg (1975), which is claimed to be the first work in the economics of religion since Adam Smith (Iannaccone, 1998). In the model of the salvation motive, they posit that a household rationally devotes their time and effort in religious activities for the expected afterlife consumption – that is, the expected afterlife benefit or reward is the factor that influence today’s choice of a household among secular and religious activities. Inversely an individual can believe that delinquent behaviors including substance use lead to the punishment in hell (or the negative consequence in the expected afterlife benefit). Then this individual’s choice is obvious; don’t do something that will direct you to the hell.

While the empirical support of the hellfire hypothesis has not been so positive for religion and delinquent behaviors (Burkett and White, 1974; Hirschi and Stark, 1969), almost every study that applies the hellfire hypothesis exclusively to religion and substance use has confirmed the existence of the negative association between two. For example, Adlaf and Smart (1985) and Hardert and Dowd (1994) find that religion deters illicit drug use more than licit one, and Cook et al. (1997) find that religion equally deters both. However, including the study of Elifson et al. (1983) which finds that religion is much more influential on victimless crime like smoking marijuana and drinking alcohol, many have argued for the ‘antiasceticism hypothesis’ that the effect of religion is particularly (or only) strong on substance use as religion is one of very few institutions that prohibit such uses but the society overall allows (Also see Albrecht et al. (1977); Burkett and White (1974); Cochran and Akers (1989); Dudley et al. (1987); Elifson et al. (1983); Hadaway et al. (1984); Khavari and Harmon (1982); Mason and Windle (2002)). Thus, although opinions on the religious effect on legal or illegal delinquent behavior differ in the literature, a consistent view at least on religion and substance use exists: There is a negative relationship between religion and substance use.

difference is whether an individual believe in sanctions in afterlife or during the lifetime shorting after the wrongdoings.

3.2.2 Reference Group Hypothesis

While the hellfire hypothesis leading to a simple bivariate association has been supported by many empirical findings, the relative strength of the relationship is subject to other contextual factors. One of contextual factors that have gotten the attention is how the religious group an individual belongs to affects the relationship between religion and substance use even as the group's norm is used as the behavioral reference (Cochran and Akers, 1989). For example, the Catholic Church has a much more liberal attitude toward substance use than the fundamental Protestant Church which may not even allow alcohol use for liturgical purpose (Cochran et al., 1992). Then, how religion and substance use relate each other would be influenced by the group characteristic on substance use and how strongly a believer is attached to the religious group. Thus, it can be conjectured that the more proscriptive a religious group that an individual belongs to the more likely an individual abstain from substance use.

Such a framework, known as the reference group hypothesis, led to a volume of studies that examine the relative effect of religion on substance use (mainly alcohol and marijuana use). For example, Cochran and his associates, using data from the General Social Surveys, continuously have found that the effect of religion on alcohol use varies by the denomination's degree of proscriptiveness and that individuals in the proscriptive denominations are less likely consume alcohol (Beeghley et al., 1990; Bock et al., 1987; Clarke et al., 1990; Cochran et al., 1988, 1992). Their conclusion has been confirmed by other works in medicine and psychology as well, and the use of specific denominational effect on substance use have been pointed as a potential method to treat substance abuser (Ahmed et al., 1994; Alexander and Duff, 1991; Carlucci et al., 1993; Koenig et al., 1994; Patock-Peckham et al., 1998).

Several studies, however, have argued for the nonsignificance of denominational context in the relationship between religion and substance use (Amoateng and Bahr, 1986; McIntosh et al., 1981). McIntosh et al. (1981) claim that the religious effect leading to less drug use is universal and consistent regardless of people's denominational association. Moreover, Jews

who, according to Cochran and associates, belong to the nonproscriptive denomination are often found much less likely to be substance abuser (Carlucci et al., 1993; Glassner and Berg, 1980). However, the mixed results over the reference group hypothesis do not dispute the negative relationship between religion and substance use. It is only whether the denominational context has any effect in the strength in such a relationship.

3.2.3 Moral Community Hypothesis

As stated above, the first application of the hellfire hypothesis to religion and general delinquent behavior by Hirschi and Stark (1969) fails to be confirmed. In contrast to the antiasceticism hypothesis, Higgins and Albrecht (1977) suggest that the failure of Hirschi and Stark (1969) is from the selection bias of using data of nonreligious northern California. After finding negative correlations between religion and 17 types of delinquent behavior using data of religious South (Atlanta, Georgia), they argue that religion is perceived differently depending on the community's religious characteristic. Thus, similar to the reference group hypothesis, the group's contextual effect – that is, the religiosity of surrounding secular communities – was called to be in operation. In sum, the moral community hypothesis states that the deterrent effect of religion requires the support of the community and becomes only significant when it is ratified the social environment (Cochran and Akers, 1989; Stark, 1996).

This has produced subsequent papers that examine aggregate religiosity in the community and substance use, and has been confirmed by Amey et al. (1996); Richard et al. (2000); Tittle and Welch (1983); Welch et al. (1991). Moreover, the moral community hypothesis has even triggered one of coauthors, Rodney Stark, who claimed the nonexistence of religious effect on delinquency to change the opinion (Stark, 1996; Stark et al., 1982).⁷ One exception seems to be the study conducted by Chadwick and Top (1993) where they report that the community's religious climate does not make any difference on the

⁷Stark (1996) note why and how his thought on religion and delinquency has changed and developed over the course of time.

religious effect on adolescent delinquency (including substance use) but that religion reduces delinquency regardless of community's religiosity.

Based the finding that the religious effect on substance use is reduced when some other contextual factors such as peer association, parental religiosity, and other family characteristics are controlled for, some have argued that the religious effect on substance use is indirect and religion is rather used as a selection mechanism that diminishes the chance to be exposed to substance use (Bowker, 1974; Burkett and Warren, 1987; Foshee and Hollinger, 1996; Kandel et al., 1976; Perkins, 1987). Such an argument does not necessarily question the validity of the negative association between aggregate religiosity and substance use. It, however, challenges the causality of the moral community hypothesis. That is, the negative association between aggregate religiosity and substance use can be actually the result of a highly religious individual choosing to live in highly religious community. Thus, although how the community's religiosity controls or interacts with individual religiosity is debatable, the negative relationship between religion and substance use is clearly supported.

As our literature review suggests, the level of the empirical support on each hypothesis differs. However, there is a consensus view on how religion and substance use are related. A stylized fact of the negative association between religion and substance use are numerous suggested by existing findings. We now turn to the annotated list of works that have empirically tested the relationship between religion and substance use.

3.3 Literature Findings: Stylized Fact

This section provides the annotated list of works that have empirically tested the relationship between religion and substance use. To clarify the consensus view that there is a negative association between religion and substance use, I enumerate them by noting the hypothesis tested, what are found, and the date that are used. In appendix D.1, I also provide a complete list of works that study the relationship between the two.

1. Adlaf and Smart (1985) looks at the relationship between religiosity and use of various licit and illicit drugs.

Findings: Roman Catholic students tended to report lesser uses of cannabis, non-medical and hallucinogenic drug use than Protestant and non-affiliated counterparts. Highly religious (stronger feeling toward religion) and more frequently church-attending students tended to report lesser uses of all types of drug except alcohol use.

The effect of religiosity and church attendance on drug use became stronger as the type of drug became more severe (or became more illicit). Also the more experience with drug use students had, the greater the effect of religiosity on drug use became.

On average, students with no feeling toward religion tended to report the use of greater numbers of illicit drug (drugs taken without medical prescriptions and hallucinogenic drugs) than ones with strong and moderate feelings.

Data or Sample Description: Data come from a sing-stage sample of 3,607 students attending regular programmes in grade 7, 9, 11 and 13 in Ontario in 1983.

2. Ahmed et al. (1994) look at the relationship between denomination affiliation and cigarette smoking.

Findings: Among a sample of African American women of childbearing age, those affiliated with the Pentecostal denomination tended to report higher rates of quitting smoking and lower rates of being current smoker when compared to others not affiliated with the Pentecostal. Those affiliated with the Pentecostal were 3.6 time and 10 times more likely than others with other denomination affiliations or without any religious affiliation to be current smokers or to quit smoking, respectively.

Data or Sample Description: Data come from a community-based sample of 266 African women (18 to 44 years of age) living in Norfolk, Virginia. It is from a larger sample of 1,018 African American adults living in same geographic area.

3. Albrecht et al. (1977) look at the relationship between religious attitude, religious

behavior, and deviance.

Findings: Mormon boys with higher scores on the religious attitudes measured by beliefs in God, Jesus, the Bible, and the devil, and on religious behaviors measured by the frequency of church and other church-related event attendance and personal prayer tended to report lower likely to have participated in victimless deviance such as cigarette/marijuana smoking and alcohol drinking than those with lower scores.

Only Mormon girls with higher scores on the religious behavior measure followed the pattern of their male counterparts on victimless deviance. For Mormon girls, religious behavior was the strongest predictor of self-reported deviance including cigarette/marijuana smoking, alcohol drinking, hard drug use, pre-marital sex, stealing, shoplifting, and fight.

Data or Sample Description: Data come from the questionnaire completed by 244 Mormon teenagers residing in six congregations in Utah and California.

4. Alexander and Duff (1991) look at the relationship between religiosity and alcohol use among retired seniors.

Findings: 30% of samples from the religious retirement community of Christianity-related service drank alcohol, while 53% of samples from the secular retirement community of secular professional drank.

In the secular retirement community, the more socially active retiree tended to report higher rates of alcohol drinking, which matched the pattern found in other retirement communities. In the religious community, the relationship between the level of social activity and alcohol drinking did not exist. The more active retiree in the religious community even reported lesser alcohol use rates than the less active retiree in the secular community.

Retirees with higher levels of personal (strong religious belief, prayer, and bible reading) and social (church affiliation and attendance) religious practice tended to be alcohol abstainers or light drinkers.

Sample or Data Description: Data come from the interview with randomly selected 156 residents living in two adjoining Southern California retirement communities: 81 subjects were from the religious community where residents were retirees of Christianity-related service of 20 or more years, while 75 subjects are from the secular community where residents were former professionals in various secular sectors.

5. Alford et al. (1991) look at the relationship between the religion-based substance abuse treatment program and rates of subsequent substance abuse.

Findings: At an initial follow-up since the release from Alcoholic Anonymous-Narcotics Anonymous based treatment program (6 months after), 71% of male and 79% of female program completers continued to be absolute or near abstainers from various substances (such as alcohol, marijuana, cocaine, stimulants, tranquilizers, analgesics, hallucinogens, and inhalants), while only 37% of male and 30% of female noncompleters did. For female samples, 70% at Year 1 and 61% at Year 2 continued to be absolute or near abstainers, while only 28% at Year 1 and 27% at Year 2 of noncompleters did.

At Year 2 after the release, either program completers or noncompleters who attended local AA/NA meetings more than once per week tended to be absolute or near abstainers than others who attended less frequently or did not.

Sample or Data Description: Data come from 157 adolescent patients (aged 13 to 19) admitted into inpatient chemical dependency unit at a major general hospital. Staff members at the unit were familiar with Alcoholic Anonymous and Narcotics Anonymous.

6. Amey et al. (1996) look at the relationship between religion and adolescent drug use depending on the racial profile.

Findings: More religious White high school seniors - that is, religiously affiliated with any denomination, more importance given to religion, and more frequently attending church - were less likely to have used substances such as cigarette, marijuana/hashish, and other illegal drugs (LAD, cocaine, amphetamines, barbiturates, tranquilizers, heroines, and etc). For alcohol use, White seniors that were affiliated with Catholic Church or

attended rarely showed more probabilities to have drunken alcohol. Black teens that attended church more frequently and gave more importance to religion tended to have lower chances to have used alcohol and marijuana/hashish.

For marijuana use, high school seniors who never attended church showed 1.37 times more likelihood to have used than those who attended at least monthly. For alcohol use, those who attended church only once or twice per month showed once or more often per week showed almost twice more likelihood to have used than those who attended at least weekly.

Sample or Data Description: Data come from 11,728 samples in the Monitoring Future: A Continuing Study of Values and Lifestyle, the annual survey of high school seniors conducted by the Survey Research Center at University of Michigan since 1975.

7. Amoateng and Bahr (1986) look at the relationship between religious participation and alcohol/marijuana use among adolescents.

Findings: Highly religious adolescents, measured by frequency of church attendance and importance of religion in one's life, were less likely to report to be heavy/more-frequent alcohol drinkers and lifetime/recent marijuana users.

Denomination-wise, Catholic adolescents had the highest frequency and amount of alcohol consumption where as Mormon counterparts had the lowest. For the marijuana use, those without any religious affiliation were most likely to be users, while, like alcohol use, Mormon adolescents were the least likely to use. Throughout various denominations, more religious adolescents tended to be less likely users of alcohol and marijuana.

The religious effect on alcohol and marijuana use among adolescents was particularly strong among Mormons than any other religious denomination. Also the religious effect was relatively stronger on marijuana use than alcohol drinking.

Sample or Data Description: Data come from over 17,000 samples in the 1982 version of the Monitoring Future: A Continuing Study of Values and Lifestyle, the annual survey of high school seniors conducted by the Survey Research Center at University of Michigan

since 1975.

8. Bahe et al. (1998) look at the religiosity, religious activity, and adolescent drug use.

Findings: Among a sample of secondary students in Utah, religiosity measured by the frequency of church visit and importance of religion in their life was negatively associated with the use of alcohol, marijuana, and amphetamines and depressants. That is, the more religious adolescents tended to be, the less likely to use these three types of drugs. The negative relationship of religiosity to alcohol was weaker than to marijuana or amphetamines and depressants.

Religiosity was also indirectly related to adolescent drug use. Adolescents involved in religion were also less likely to associate with drug-using peers whereas having drug-using peers was found to be the strongest predictor of adolescent drug use. The more religious adolescents tended to be, the less likely to have friends who drink alcohol or use drugs.

Sample or Data Description: Data come from the 13,250 in-school questionnaires completed by randomly selected secondary school students in grades 7-12 in Utah during 1994.

9. Beeghley et al. (1990) look at the relationship between religiosity, religious affiliation, and alcohol consumption.

Findings: 46% of those belonged to and stayed at proscriptive denominations (such as Baptists, Fundamentalists, Evangelicals, and Pentecostals) against alcohol use reported alcohol nonuse, while 41% of those who moved to the proscriptive denominations from the nonproscriptive denominations (such as Catholics, Jews, Episcopalians, Presbyterians, Lutherans, and Methodists), 23% of those who moved to the nonproscriptive denominations from the proscriptive denominations, and 17% of those who belonged and stayed at the nonproscriptive denominations reported nonuse.

Strongly religious persons (measured by church attendance, strength of religious identification, church membership, and belief in afterlife) tended to report more likely to

abstain from or not to misuse alcohol than weakly religious counterparts. Also among strongly religious and weakly religious persons, those who stayed at the proscriptive denominations had the highest predicted chance not to use alcohol whereas those who moved to the proscriptive groups, those who moved to the nonproscriptive groups, and those who stayed at the nonproscriptive groups followed in a descending order of their predicted chances.

Those who stayed at the proscriptive faith groups tended to have the greatest religious inhibitory effect on alcohol use than others. Also the probability of misusing alcohol decreased as persons belonged to more proscriptive denominations.

Sample or Data Description: Data come from 8,652 adult samples in U.S., drawn from the General Social Surveys (GSS) in 1977, 1978, 1980, 1983, 1984, and 1986 (years when alcohol consumption was asked).

10. Benda and Corwyn (1997) look at the relationship between religiosity, status offenses and crime.

Findings: Among adolescents, more frequent attendance/involvement with church and more personal practice in religion such as bible study and prayer tended to lead to lower levels of status offenses including alcohol use, running away, fake excuses for absences from school, and skipping school.

More adolescent evangelism - that is, religious talking with family and friends, discussing religious joys and problems, and attempting for others' conversion - tended to reduce the level of crimes such as property (breaking and stealing) and person (fight and robbery) crimes and use of illegal drugs (cocaine, opiates, barbiturates, amphetamines, and marijuana).

Sample or Data Description: Data come from the questionnaire completed by randomly selected 724 high school students (grades 9-12) residing in Little Rock, Arkansas, rural Arkansas, and Arkhoma, Oklahoma.

11. Bock et al. (1987) look at the relationship between religiosity, religious denomination and alcohol use/misuse.

Findings: 90% of persons without any religious affiliation reported to be alcohol users, while 87% of Episcopalians, 86% of Catholics, 85% of Lutherans and Jews, 78% of Presbyterians, 68% of Methodists, and 56% of Baptists and other conservative Protestants (such as fundamentalists) did so. The proportion to misuse alcohol was also the highest among persons without any religious affiliation where 50% of them reported alcohol misuse.

Persons with higher religiosity measured by strength of religious identification, church attendance, and church membership tended to report lesser amounts of alcohol use. Also among those affiliated with Conservative Protestants - that is, Methodists, Baptists, and members of other Protestant sects - religiosity was found to have a clear inhibitory effect on alcohol consumption.

Sample or Data Description: Data come from about 4,000 adult samples of U.S., drawn from the General Social Surveys (GSS) in 1977, 1978, and 1980 (years when alcohol consumption was asked).

12. Brizer (1993) looks at the relationship between religiosity and drug/alcohol consumption among chemically dependent inpatients.

Findings: In the comparison of two populations, those admitted to the chemical dependence unit vs. the general psychiatric unit, inpatients in the general unit were more likely to avoid certain food/music/drink because of religious reason and to help church-related activities than ones in the chemical dependence unit.

Also among inpatients in both units, various measures of religiosity were found to be negatively and significantly related to the use of alcohol and drugs; 1) patients who avoided certain food/music/drink because of religious reason or who believed in the communication with God tended to report lesser consumptions of alcohol in the precedent month of the questionnaire completed, 2) patients who believed in supernatural's

interfere with behavioral decision tended to report lesser uses of hallucinogen, 3) patients whose religion suppressed the consideration of suicide or who attended church more frequently tended to report lesser uses of any prescription drug, 4) in the past year, patients who had kept the faith tended to report lesser uses of stimulants than those who had not, 5) patients who were affiliated with any religion tended to report lesser uses of alcohol, and 6) in the past year, patients whose parents were affiliated with any religion tended to report lesser uses of opiates.

Sample or Data Description: Data come from the religion and drug/alcohol questionnaire completed by 168 adult inpatients admitted into either the chemical dependence (63 patients) or general psychiatric unit (105 patients) at a private psychiatric hospital located in Salt Lake City, Utah.

13. Brownfield and Sorenson (1991) look at the relationship between religion and adolescents drug use.

Findings: While only 11.2% of those unaffiliated with any religion reported to be abstainers of drugs (such as alcohol, marijuana, barbiturates/methedrine, psychedelics, and cocaine) or users of alcohol only, 20.0% of those affiliated with Catholic, Jewish, or Protestant Church reported to be such limited drug users. Among the religious affiliated, 23.1% of the Protestants reported to be abstainers of drugs of users of alcohol only compared to 15.2% of those with the Catholic Church.

Contrast to 22.5% of those who never attended church, reporting to use all of alcohol, marijuana, barbiturates/methedrine, psychedelics, and cocaine, only 6.4% of those attended church more than once per week reported so. Also contrast to 19.6% of those who reported not to be religious at all reporting use all drug types mentioned above, only 19.6 of those who reported to be very or somewhat religious did so.

Sample or Data Description: Data come from 800+ white male samples, which were parts of the Seattle Youth Study, a larger high school student dataset of the Seattle school district collected by the University of Washington.

14. Burkett and Warren (1987) look at the relationship between religion and adolescent marijuana use.

Findings: The commitment to religion (measured by church attendance, religious satisfaction, and strength of religious belief) and the belief that marijuana use was sinful indirectly affected marijuana use by preventing the association with marijuana-using peers. Also these religious effects became stronger throughout time as the religious commitment reinforced the belief that marijuana use was sinful. Before being associated with marijuana-peers, adolescents first tended to report to lower their religious commitment.

Sample or Data Description: Data come from the self-administered subsequent two questionnaires completed by 264 high school students during their final 3 years (grade 10-12) who resided in a medium-sized city in the Pacific North West.

15. Burkett and White (1974) look at the relationship between religion and adolescent delinquent behaviors including alcohol and marijuana use.

Findings: While the frequency of church attendance was only weakly associated with adolescent delinquent behaviors such as larceny, vandalism, and assault, frequent church attendance showed a definite negative relationship with the use of alcohol and marijuana use.

As adolescents attended church more often, they tended to agree that alcohol and drug uses were sinful, which was also strongly related to the belief in supernatural sanctions. Such agreement and belief showed a significant negative relationship with alcohol and marijuana use.

Sample or Data Description: Data come from questionnaires completed by 434 male and 421 female Caucasian seniors attending three Pacific Northwest high schools in the spring of 1971.

16. Carlucci et al. (1993) look at the relationship between religious affiliation and drink-related delinquencies.

Findings: Among college students, Catholics tended to report more alcohol-related problem behaviors (such as driving or fighting after having too much drink) than Protestants and Jews.

Sample or Data Description: Data come from the questionnaire completed by 331 students (age 28-24) enrolled at three colleges in the Eastern U.S.

17. Carroll (1993) looks at the relationship between the spirituality-base recovery program of alcoholism and abstinence from alcohol use.

Findings: Among members of Alcoholics Anonymous (AA) groups, more practice of Step 11 (that recommended more prayer and meditation) and Step 12 (that recommended the help to other alcoholics and attendance at AA meetings) indirectly affected the length of sobriety to increase through its direct impact to higher the sense in meaning/purpose in life. As members attended the AA meeting more frequently, their length of sobriety was found to increase as well.

Sample or Data Description: Data come from the questionnaire completed by 100 adult participants in 20 Alcoholic Anonymous groups in northern California.

18. Cochran (1992) looks at the relationship between individual religiosity and frequency of adolescent drug use.

Findings: As adolescents became more religious and the participation in the church-related activity became more important to them, they tended to use stimulants, depressants, psychedelics, narcotics, and marijuana less frequently. Also the effect of religiousness and church-related activity participation did not vary or was stable over various types of drug

Sample or Data Description: Data come from the questionnaire completed by 3,065 students (grade 7-12) attending 23 secondary schools in 7 school districts in 3 Midwestern states during 1970s. Data was originally collected by Akers and Krohn where the Boys Town Center for the Study of Youth Development in Boys town, Nebraska supported.

19. Cochran and Akers (1989) look at the relationship between various measures of religion and adolescent use of alcohol and marijuana.

Findings: Adolescents who were religious, put more importance on church-related activities, and accepted the proscriptive norm set by religion are less likely to use alcohol and marijuana than those weakly religious.

Strongly religious adolescents who belonged to the proscriptive denomination (such as Baptist, Methodist, or Pentecostal) were less likely to use alcohol than those who belonged to the nonproductive (such as Catholic, Jewish, Episcopalian, Lutheran, Presbyterian, or no religious affiliation) but strongly religious. The religious effect on adolescents marijuana use did not vary or was consistent across the proscriptive and the nonproscriptive.

Among adolescents who lived in high religious community (in which the majority claimed to be strongly religious), the higher level of their religiousness, participation importance, and acceptance of the proscriptive norm tended to lead to a lesser frequency of alcohol and marijuana use. Also strongly religious adolescents living in low religious community were less likely to drink alcohol than those in the high religious community. Yet, again the religious effect on adolescents marijuana use did not vary or was consistent across high and low religious communities.

Sample or Data Description: Data come from the questionnaire completed by 3,065 students (grade 7-12) attending 23 secondary schools in 7 school districts in 3 Midwestern states during 1970s. Data was originally collected by Akers and Krohn where the Boys Town Center for the Study of Youth Development in Boys town, Nebraska supported.

20. Cook et al. (1997) look at the relationship between religiosity and substance use among young people in the United Kingdom.

Findings: Persons who was committed to Jesus, usually went to church on Sunday, read the Bible weekly, prayed daily had lower chances to being offered or having used drugs (such as Cannabis, stimulants, and hallucinogens) than those did not. More persons

tended to have used drugs five or more times as they were less committed to religion.

Sample or Data Description: Data come from the questionnaire completed by 7,666 church-affiliated young people (age 12-30) who attended Spring Harvest in 1995 in the United Kingdom. Spring Harvest in 1995 was held in Minehead, Skegness, and Ayr, and is annual interdenominational-evangelical event.

21. Forthun et al. (1999) look at the relationship between religion and alcohol/marijuana use among college students.

Findings: Among college students in southwest U.S., higher religiosity (measured by church attendance during their high school years) and being affiliated with Conservative Protestant churches (such as Pentecostal) predicted either the lower level of current alcohol/marijuana use or the later first use of alcohol. Particularly religiosity was found to have a strong effect on alcohol and marijuana use than religious affiliation.

Sample or Data Description: Data come from the questionnaire completed by 526 single white students enrolled at a state-supported southwestern university.

22. Francis (1997) looks at the relationship between religion and attitude towards substance use among English adolescents.

Findings: Among those with same social backgrounds of sex, age, social class, and personality, persons of the stronger belief in God tended to report a much less tolerant attitude towards substance use. Also among those with same social backgrounds as above and with same level of personal religiosity measured by church attendance, prayer, and belief in God tended to report a much less tolerant attitude towards substance use.

Sample or Data Description: Data come from the questionnaire completed by 11,163 high school students (grade 9 and 10) living in England and Wales.

23. Francis (2002) looks at the relationship between Belief in God, Bible reading, and attitudes towards substance use among English adolescents.

Findings: As English adolescents believed in God more strongly and read the Bible

more frequently, they tended to adopt a negative stance against drug use (such as cigarette/marijuana smoking, alcohol drinking, heroin use, and glue/butane-gas inhale). Also among those who believed in God strongly, adolescents who read the Bible more frequently tended to develop a more negative attitude toward drug use than those who did not.

Sample or Data Description: Data come from the questionnaire completed by 25,888 high school students (grade 9-10) enrolled in 128 secondary schools in England and Wales.

24. Hardert and Dowd (1994) look at the relationship between religiosity and alcohol/marijuana use.

Findings: High school and college students who considered they were religious had about one-half odds to use marijuana than those who did not, while the religiosity did not contribute much to alcohol use.

Sample or Data Description: Data come from the questionnaire completed by sampled 1,234 high school and college students residing in suburban areas in Phoenix, Arizona

25. Koenig et al. (1994) look at the relationship between religious behaviors and alcohol abuse among adults living in North Carolina.

Findings: Adults who engaged in private religious activities (such as prayer and Bible reading) more than several times per week were about twice more likely not to experience alcohol abuse or dependence within the last six-month than those who engaged less often. Also adults who attended church at least once a week were about three times (twice) more likely not to experience alcohol abuse or dependence within last 6-month (lifetime) than those who attended less often.

Adults with having life-turning religious experience tended to have lower six-month and lifetime rates of alcohol disorder than ones without. Also the conservative-Protestants affiliates (Baptists) tended have lower lifetime rates of alcohol disorder than the

Pentecostal, Catholic, Greek Orthodox, and no religion affiliates.

Sample or Data Description: Data come from two-stage interviews in 1982 and 1983 with 2,969 adults living in five counties in east-central North Carolina. Data represent the Piedmont part of multi-state Epidemiologic Catchment Area (EAC) survey conducted by the National Institute of mental Health.

26. Luczak et al. (2002) look at the relationship between religion and binge drinking among college students.

Findings: Jewish subjects (who attended the religious service on average 11.2 times and on median 4 times, and of which 17% did not attend the religious service in the precedent year) tended to report less chances of binge-drinking than non-Jewish white counterparts (who attended the religious service on average 9.8 times and on median 2 times, and of which 40% did not attend the religious service in the precedent year).

Among Jewish samples, Jews who reported to be secularly Jewish - that is, religiously affiliated with others than Reconstructionist or Conservative - were three times more likely to binge drink than Jews who reported to be religiously Jewish affiliated with Reconstructionist or Conservative.

Sample or Data Description: Data come from 279 college students with Ashkenazic Jewish (132) and non-Jewish white (147) biological heritages, recruited at the University of California, San Diego.

27. Mason and Windle (2002) look at the relationship between religiosity, alcohol use and abuse, and alcohol-related problems among adolescents.

Findings: Among adolescents, those who attended religious activities frequently tended to report lower frequency and quantity of alcohol drinking.

As adolescents attended religious activities frequently, their future frequency-quantity of alcohol drinking tended to decrease. Also current level of alcohol use tended to suppress adolescents religiosity - that is, lower frequency of attending religious activity and lower

importance given to the religion.

Sample or Data Description: Data come from two-stage questionnaires (1-year interval) completed by 840 adolescents enrolled at high schools in a school district in western New York. Data represent a part of the larger four-stage panel data for 1,175 high school students in two school districts.

28. Richard et al. (2000) look at the relationship between (individual and communal) religiosity and the abstinence from the substance-use after the participation in publicly funded treatment programs.

Findings: After the release from the drug treatment program, those who attended church more frequently than prior to the program reported the reduced use of crack cocaine and alcohol. The increase in the attendance of various 12-step programs, the religious-principle-base recovery groups, also was found to have a reducing effect on alcohol use.

Sample or Data Description: Data come from during-program and follow-up interviews with randomly selected 190 subjects who participated in the drug treatment program at the Houston Recovery Campus (HRC) in Houston, Texas in 1994.

3.4 Conclusion

In this paper, I have provided the review of a large literature that tests the relationship between religion and substance use. This paper, first, identifies three hypothesis that explain the negative association of religion and substance use; hellfire, reference group, and moral community hypothesis. The logic of three hypothesis is explained and some of their empirical findings are mentioned. This paper also enumerates actual findings and data sources of previous empirical results in the literature. There is much larger literature in sociology, psychology, and medicine, but by observing what I provide in the paper, future research on this topic may benefit from the summary.

Main issue left is how the consensus view on the negative association between religion

and substance use can be explained through the lens of the rational addiction model. I have suggested that there are three effects of religious activity on hindering or suppressing the intensity for the appetite of substance: First, as the consumption capital from substance use is dissipated by religious practice, current substance use is much less enforced from past use. Second, as the satisfaction gap between a given level of substance use in past and today becomes narrower, higher level of past substance use leads to much less loss in the utility from current substance use. And third, the reduction or interruption in current substance use does not result in the reduction in utility. Further research and refinement of the theory suggested in previous chapters may provide an alternative and clear explanation on the religious effect on substance use.

Appendix A: Summary of Main Results

A more consistent and comprehensive vocabulary: Economic studies of habit formation make heavy use of terms borrowed from medicine and psychology. But economists have failed to adequately link these terms to their formal models and empirical results.

My first essay provides well-defined and intuitively appealing formal definitions for many different terms, including “addiction,” “myopia,” “reinforcement,” “tolerance,” and “withdrawal.” Better vocabulary leads to better research. For example, I show that some long-running debates are purely semantic (including some arguments over changes in “tastes” versus changes in stocks of “consumption capital”). I also show that inadequate definitions have some fruitful lines of research (including studies of semi-myopic behavior)

Scaling and Prolonging Effects: A major implication of the rational addiction model is that, contrary to most claims about addiction, harmfully addictive goods will have relatively high long-run price-elasticities. The model also predicts that price elasticity may be larger still for strongly-addictive commodities, which can have multiple (rational) equilibria.

My first essay shows that as addiction becomes stronger, two distinct effects work to increase the likelihood of multiple equilibria. The first is a scaling effect, which broadens the price range over which multiple equilibria can exist, thereby increasing the likelihood of a price-induced consumption jump from one equilibrium to another. The second is a prolonging effect, which induces a larger consumption response to any given price change. I suspect that previous authors (including Becker and Murphy, 1988) failed to distinguish these effects because they worked with quadratic utility functions, which eliminate the possibility of multiple equilibria.

Quasi-Myopia: In the 1970s, several economists extended standard econometric work on intertemporal consumption by incorporating the effect of (non-rational) myopic habit formation. But work on myopic models ceased after Iannaccone (1986), Becker and Murphy

(1988), and others explored the formal properties of rational addiction. More recent work in behavioral economics has revived interest in the relation between myopia and addiction, but this has induced yet another analytic jump, from models of rational addiction to models of time-inconsistent behavior due to hyperbolic discounting.

My first essay introduces the concept of quasi-myopia and so as to provide a more comprehensive framework for the study of habit formation. This framework includes total myopia and perfect rationality as special cases along a continuum of consumer foresight. Within this model, the degree of foresight regarding habit formation is a parameter that ranges from zero (in the case of total myopia) to one (in the case of perfect rationality). Thus formal analysis of the model yields results that can be used in applied econometric work to estimate different levels of myopia across different types of commodities and different types of people.

Behavioral Equivalence: The first essay also shows that the quasi-myopic model can also capture the behavior modeled via quasi-hyperbolic discounting. Indeed, the two models yield exactly the same consumption paths if the degree of time-inconsistency in the quasi-hyperbolic model equals the degree of myopia in the quasi-myopic model. This is a surprising result given the current preference for hyperbolic discounting in studies of compulsive behavior and habit formation.

Quasi-Myopia versus Hyperbolic Discounting: Although my model of quasi-myopic behavior can capture the behavior predicted by (quasi-) hyperbolic discounting, the quasi-myopic model is actually much more general. The latter family of models, applies a single (time-inconsistent) discount factor to the entire instantaneous utility function. Hence, all goods are equally subject to problems of time-inconsistency, compulsive consumption, and/or lack of foresight. (The literature obscures this fact by focusing on time-inconsistent consumption of harmful goods, such as cigarettes and cocaine.) But the quasi-myopic framework permits the consumer to have different levels of foresight regarding

different goods - perhaps because the future benefit or harm from consuming some goods is easier to observe, or because information about their consequences is more readily available.

Rules of Thumb and “Realistic” Models of Habit Formation: The rational addiction models consumption paths as solutions to a very complex optimal control problem. Proponents of the rational addiction framework have never demonstrated any straightforward way to compute these solutions. Indeed, their own results are largely limited to existence results and qualitative results in the neighborhood of steady-states. Hence, many people question the real-world relevance of such models.

My (preliminary) results demonstrate that relatively simple rules of thumb can guide consumers toward choices that approximate the optimal paths analyzed in the rational-addiction literature. Moreover, these results provide insight into the types of habits and/or types of conditions which more readily lead to the avoidance of harmful habits and the accumulation of beneficial habits. The “rules of thumb” approach thus rehabilitates rational addiction model and enhances to its predictive content.

Multiple Addictions: The second essay generalizes the standard rational addiction framework by incorporating multiple addictions. Within this framework, current consumption $(c_{1t}, c_{2t}, \dots, c_{nt})$ alters many different habit stocks (S_{1t}, \dots, S_{mt}) , and each of these habits can have different impact on future tastes for different commodities. Hence, c_1 can increase “dependence” on c_2 (as in the case of so-called “gateway” drugs) and c_3 can decrease “dependence” on c_2 (thereby helping to avoid and “break” addiction to c_2).

Generalized Adjacent Complementarity: The multiple addiction model is much more complex than the standard model, in which all habits are commodity specific. Nevertheless, I am able to generalize the simple framework’s fundamental result concerning the determinants of rational addiction.

In the standard model, rational addiction to a particular commodity occurs

when intertemporal preferences for that display a sufficiently high level of adjacent complementarity (Iannaccone 1986, Becker and Murphy 1988). The degree of “adjacent” versus “distant” complementarity measures the way in which current consumption affects future preferences. For example, if food displayed adjacent complementarity, then a person expecting a heavy dinner would want to make his lunch heavy heavier relative to his breakfast. In fact, of course, food tends to display distant complementarity.)

My analysis extends adjacent complementarity and its consequences to the realm of multiple habits. In particular, I show that a rational consumer will become addicted to goods that display sufficiently strong generalized (or “gross”) adjacent complementarity. Gross adjacent complementarity is a hierarchical extension in the concept of adjacent complementarity to the multiple habits framework; hence, it collapses down to the standard result when habits are all commodity-specific.

Applying the Multiple Addiction Model to the Demand for Religion and Substance Abuse: The third essay applies the multiple addiction framework to a particular category of behavior observed in the real-world. There exists a substantial literature analyzing the health effects of religious beliefs and participation. (For the most part, the beneficial health effects of religion seem to persist even after controlling carefully for potential sources of spurious correlation.) One of the more striking findings is that religion seems to help people avoid addictions and break addictions. My third essay shows that the multiple-addiction model provides a straightforward way in which to model observed behavior. In principal, it also provides a framework for empirical tests - one that is derived directly from economic theory rather than ad hoc regression equations.

Appendix B: For Addiction, Myopia, and Inconsistency: A Critical Review

B.1 Variable and Model Description

This appendix provides the definition of the mathematical notations and assumptions of the models that are discussed in the paper. The purpose is to clarify the meaning of variables, functions, and assumptions so that the readability of the models is enhanced.

1. STANDARD MODEL OF INTERTEMPORAL CONSUMPTION

Consumption: c is a vector of consumptions in \mathbb{R}^n , $c \in \{c_1, \dots, c_n\}$.

Costate Variable: μ is the costate variable or shadow price of the wealth A .

Price: p is a (monetary) price vector of consumption, c , in \mathbb{R}^n , $p \in \{p_1, p_2, \dots, p_n\}$; p_i is the monetary price of the i^{th} consumption or c_i .

Rate of Interest: r is the market rate of interest.

Rate of Time Preference: Let $\phi(t; t_0)$ be a discount function applied to discount future utility at a period t in t_0 . $\rho(t; t_0) = \phi'/\phi$ is a subjective rate of time preference at a period t in t_0 where $t \geq t_0$. $\dot{\rho} = 0$ implies that the system of intertemporal preferences displays the stationarity property. If $\dot{\rho} \neq 0$, the system of intertemporal preferences is no longer stationary.

Utility Function: $u(c)$ is assumed to be concave in c .

Wealth: A_0 is the initial level of wealth available for consumption to an individual.

2. THEORY OF RATIONAL ADDICTION

Consumption: c is a vector of consumptions in \mathbb{R}^n , $c \in \{c_1, \dots, c_n\}$.

Consumption Capital or Habit: S is a vector of consumption capitals or habits in \mathbb{R}^m , $S \in \{S_1, \dots, S_m\}$ where $m \leq n$. A consumption capital is a state variable that reflects past consumptions of an individual.

Commodity-Specificity: Habits are called *commodity-specific* if for each S_i there exists a unique commodity, call it c_i such that

- a. f^i depends only on the pair of (c_i, S_i) and
- b. the marginal rate of substitution of c_i to S_i , u_{c_i}/u_{S_i} , depends on the pair of (c_i, S_i) .

Costate Variable: λ is a vector of costate variables or shadow prices of consumption capitals, S . μ is the costate variable or shadow price of the wealth A .

Depreciation Rate of Capital: δ is a diagonal matrix with $\delta_i \geq 0$, and δ_i is the depreciation rate of S_i .

Formation of Habit: The habit-formation process follows

$$\dot{S} = f(c(t)) - \delta S(t) \quad (1.4)$$

where $f = (f^1, \dots, f^m)$ and $f^i(\cdot)$ is concave, non-negative, and non-decreasing in c .

Price: p is a (monetary) price vector of consumption, c , in \mathbb{R}^n , $p \in \{p_1, p_2, \dots, p_n\}$; p_i is the monetary price of the i^{th} consumption or c_i .

Rate of Interest: r is the market rate of interest.

Rate of Time Preference: ρ is the subjective rate of time preference and is assumed to be constant over time, $\dot{\rho} = 0$.

Utility Function: The instantaneous utility, $u(\cdot)$ is concave in c and S .

Wage Function: The instantaneous wage, $w(\cdot)$, takes same argument of $u(\cdot)$ in S .

Wealth: A_0 is the initial level of wealth available for consumption to an individual.

3. THEORY OF COMPULSIVE CONSUMPTION

Consumption: a is the consumption of habit-forming or addictive good, and c is the consumption of non-addictive good.

Consumption Capital or Habit: S is the consumption capitals or habits. A consumption capital is a state variable that reflects past consumptions of an individual.

Depreciation Rate of Capital: δ is the the depreciation rate of S .

Formation of Habit: The habit-formation process follows

$$S(t+1) = (1 - \delta)(S(t) + a(t)) \quad (1.12a)$$

Income: $y(t)$ is the income given at a period t and is assumed to be fully consumed at t (i.e., there is no saving problem) where

$$y(t) = c(t) + p(t)a(t) \quad (1.12b)$$

Intertemporal Preference Structure: The future utilities are evaluated at a period t either as

$$\sum_{\tau=t+1}^T \left(\frac{1}{1+\rho} \right)^\tau U(\tau) \text{ if stationary, or } \beta \sum_{\tau=t+1}^T \left(\frac{1}{1+\rho} \right)^\tau U(\tau) \text{ if nonstationary} \quad (1.11')$$

where $\beta \in [0, 1]$ captures the feature of hyperbolic discounting.

Price: p is the relative price of consumptions, a to c where the price of c is normalized to 1. It is assumed to be constant over time, $\dot{p} = 0$.

Rate of Interest: r is the market rate of interest. It is assumed to be constant over time, $\dot{r} = 0$.

Utility Function: The instantaneous utility, $U(t)$ is separable in $u(a(t), S(t))$ and $v(c)$. Both are concave in a , S , and c , respectively.

4. A SIMPLE MODEL OF MYOPIC ADDICTION

The notations in the model of myopic and quasi-myopic addiction are same as above for

the theory of compulsive addiction, except

Intertemporal Preference Structure: The future utilities are evaluated exponentially at a period t as

$$\sum_{\tau=t+1}^T \left(\frac{1}{1+\rho} \right)^{\tau} U(\tau) \quad (1.20')$$

Formation of Habit: The actual habit-formation process follows

$$S(t+1) = (1-\delta)(S(t) + a(t)) \quad (1.12a)$$

but when the consumption is planned at a period t , it is assumed to follow

$$S^{\circ}(t+1) = \eta(1-\delta)a(t) + (1-\eta\delta)S(t) \quad (1.22)$$

where $\eta \in [0, 1]$ represents the degree of myopic about the habit-formation.

B.2 Mathematical Economics of Addiction

This appendix provides the mathematical and economic models in intertemporal choice and addiction literature. The reviewed results and figures are often the direct consequences of derivations provided here.

Standard Model of Intertemporal Choice, á la Samuelson (1937): The maximization provided by (1.1) subject to (1.2) is a lifetime maximization problem with an integral constraint. As Chiang (1992, pp. 282–4) notes, it requires the conversion of the integral constraint into an equation of motion. To replace the lifetime wealth constraint and its

boundary conditions with a new state variable, I introduce

$$\Gamma(\tau) = - \int_0^\tau p(\tau)c(\tau)e^{-r\tau} d\tau.$$

The derivative of it with respect to time leads to the equation of motion

$$\dot{\Gamma} = -p(\tau)c(\tau)e^{-r\tau}, \quad (\text{B.1})$$

of which initial and terminal values for the boundary condition are

$$\Gamma(0) = - \int_0^0 p(\tau)c(\tau)e^{-r\tau} d\tau = 0 \quad \text{and} \quad \Gamma(T) = - \int_0^T p(\tau)c(\tau)e^{-r\tau} d\tau \geq -A_0. \quad (\text{B.2})$$

Using (B.1) and introducing a current-valued costate variable μ , I write the current-valued Hamiltonian,

$$H = u(c) - \mu p c e^{-rt}. \quad (\text{B.3})$$

(The time subscript is dropped for the readability of the model.) It is immediately followed by the necessary and transversality conditions,

$$H_c = u_c - \mu p e^{-rt} = 0 \quad (\text{B.4})$$

and

$$\dot{\mu} - \rho\mu = -H_\Gamma = 0 \quad (\text{B.5})$$

$$\Gamma(T) + A_0 \geq 0, \quad \mu e^{-\rho T} (\Gamma(T) + A_0) = 0.$$

From the Pontryagin's maximum principle, I know that the solution that satisfies (B.1), (B.4), and (B.5) is sufficient to guarantee the optimality of solution. Furthermore, (B.4) shows that along the optimal path of c , the Hamiltonian is maximized with respect to c at

each moment, showing the standard optimal condition that the marginal benefit and cost are equal.

As the path of c is time-differentiable and assuming $\dot{p} = \dot{\rho} = \dot{r} = 0$, I may differentiate (B.4) with respect to time and obtain

$$\dot{c} = u_{cc}^{-1}(\dot{\mu} - r\mu)pe^{-rt}. \quad (\text{B.6})$$

As u_{cc} is negative definite and combining (B.6) with $\dot{\mu} = \rho\mu$ from (B.5) leads to

$$\dot{c} = u_{cc}^{-1}(\rho - r)\mu pe^{-rt},$$

the sign of \dot{c} depends on the relative size of the rate of time preference to the rate of interest.

It is clear that

$$\dot{c} > 0 \text{ when } \rho < r, \quad \dot{c} < 0 \text{ when } \rho > r, \quad \dot{c} = 0 \text{ when } \rho = r,$$

a result that is consistent with common intuition.

For the simplicity of analysis and as it is the case where the wealth bears no purpose other than consumption, I may concentrate on the case of $\rho = r$ and identify the optimal consumption path. As $\dot{p} = \dot{\rho} = \dot{r} = \dot{c} = 0$ and $\rho = r$, I can specify the optimal consumption path that satisfies (B.2) as

$$c^*(\cdot) = \left(\frac{rA_0}{1 - e^{-rT}} \right) p^{-1}$$

which is accompanied by

$$\mu^* = u_c(c^*)p^{-1}e^{rt} \quad \text{and} \quad \dot{\Gamma}^* = \frac{-rA_0e^{-rt}}{1 - e^{-rT}}.$$

μ^* is the current-valued marginal utility of wealth, and $\dot{\Gamma}^*$ is the rate of wealth dissipation.

Model of Rational Addiction, á la Becker and Murphy (1988): The maximization provided by (1.3) subject to (1.4), (1.5), and (1.6) is also a lifetime maximization problem with an integral constraint. To replace (1.5) and (1.6) with a new state variable, I introduce

$$\Gamma(\tau) = - \int_0^t p(\tau)c(\tau)e^{-r\tau} d\tau + \int_0^t w(S(\tau)) e^{-r\tau} d\tau.$$

The derivative of it with respect to time leads to the equation of motion

$$\dot{\Gamma} = -p(\tau)c(\tau)e^{-r\tau} + w(S(\tau)) e^{-r\tau}, \quad (\text{B.7})$$

of which initial and terminal values for the boundary condition are

$$\begin{aligned} \Gamma(0) &= - \int_0^0 p(\tau)c(\tau)e^{-r\tau} d\tau + \int_0^0 w(S(\tau)) e^{-r\tau} d\tau = 0, \\ \Gamma(T) &= - \int_0^T p(\tau)c(\tau)e^{-r\tau} d\tau + \int_0^T w(S(\tau)) e^{-r\tau} d\tau \geq A_0. \end{aligned} \quad (\text{B.8})$$

Using (1.4) and (B.7), and introducing a current-valued costate variable μ and a vector of current-valued costate variables λ , I write the current-valued Hamiltonian,

$$H = u(c, S) + \lambda(f(c) - \delta S) + \mu(-pce^{-rt} + w(S)e^{-rt}). \quad (\text{B.9})$$

(The time subscript is again dropped for the readability of the model.) It is immediately followed by the necessary conditions,

$$H_c = u_c + \lambda f_c - \mu p e^{-rt} = 0, \quad (\text{B.10})$$

$$\dot{\lambda} = -H_S + \rho\lambda, \quad \text{and} \quad \dot{\mu} - \rho\mu = -H_\Gamma = 0 \quad (\text{B.11})$$

with transversality conditions,

$$\lambda(T)e^{-\rho T}S(T) = 0, \quad \Gamma(T) + A_0 \geq 0, \quad \text{and} \quad \mu e^{-\rho T}(\Gamma(T) + A_0) = 0. \quad (\text{B.12})$$

From the Pontryagin's maximum principle, I know that the solution that satisfies (B.10), (1.4), (B.11), eq:beckerbound1, and (B.12) is sufficient to guarantee the optimality of solution.

As the first in (B.11) suggests the shadow price of a habit, S_i , to be

$$\dot{\lambda}_i - (\delta_i + \rho)\lambda_i = -u_{S_i} - \mu w_{S_i} e^{-rt},$$

and the latter in (B.11) implies that $\mu e^{-\rho t}$ is a constant, I may multiply $e^{-(\delta_i + \rho)t}$ and integrate both sides from t to T with respect to τ and arrive at

$$\begin{aligned} \int_t^T e^{-(\delta_i + \rho)(\tau - t)} \left(\dot{\lambda}_i - \lambda_i(\rho + \delta_i) \right) d\tau &= \left[e^{-(\delta_i + \rho)(\tau - t)} \lambda_i \right]_t^T \\ &= -\lambda_i(t) = - \int_t^T e^{-(\delta_i + \rho)(\tau - t)} u_{S_i} d\tau - \mu e^{-\rho t} \int_t^T e^{-(\delta_i + \rho)(\tau - t)} w_{S_i} d\tau. \end{aligned} \quad (\text{B.13})$$

It shows that λf_c is the *future* consequence of current consumption c .

As the path of c is time-differentiable and assuming $\dot{p} = \dot{\rho} = \dot{r} = 0$ and $\rho = r$, I differentiate (B.10) with respect to t and obtain

$$\dot{c} = -H_{cc}^{-1} u_{cS} \dot{S} - H_{cc}^{-1} f_c \dot{\lambda} \quad (\text{B.14})$$

that leads the maximized Hamiltonian $H^\circ = \max_c H$.

Using H° from (B.14), the linear approximation to (1.4) and (B.11) yields the following system that describes the dynamic behavior nearby the neighborhood of the stationary

point,

$$\dot{x} = M(x^*)(x - x^*) \text{ where } x = \begin{pmatrix} S \\ \lambda \end{pmatrix} \text{ and } M = \begin{pmatrix} H_{\lambda S}^\circ & H_{\lambda\lambda}^\circ \\ -H_{SS}^\circ & \rho I - H_{S\lambda}^\circ \end{pmatrix}.$$

M is the Jacobian derivative that is originally a $(2m + 2) \times (2m + 2)$ matrix but is reduced to a $2m \times 2m$ matrix: It is because $\dot{\Gamma}$ and $\dot{\mu}$ can be omitted at no loss, as long as the transversality condition of Γ , (B.8), is met and that $\mu e^{-\rho t}$ is a nonnegative constant is kept in mind (Chiang, 1992, p. 282). Furthermore, when habits are commodity-specific, the H and f matrices are diagonalized and the motion of the pairs in (S_i, λ_i) is independent from others. Then the dynamic behavior nearby the stationary point is characterized by a subsystem

$$\begin{pmatrix} \dot{S}_i \\ \dot{\lambda}_i \end{pmatrix} = \begin{pmatrix} -\delta_i - H_{c_i c_i}^{-1} f_{c_i}^i u_{c_i S_i} & -H_{c_i c_i}^{-1} (f_{c_i}^i)^2 \\ -H_{S_i S_i} + H_{c_i c_i}^{-1} (u_{c_i S_i})^2 & (\delta_i + \rho) + H_{c_i c_i}^{-1} f_{c_i}^i u_{c_i S_i} \end{pmatrix} \begin{pmatrix} S_i - S_i^* \\ \lambda_i - \lambda_i^* \end{pmatrix}. \quad (\text{B.15})$$

where $u_{c_i S_i} = H_{c_i S_i}$.

Letting M_i be the submatrix of M for the pair of (S_i, λ_i) , the characteristic equation has the form

$$\det(M_i - \beta_i I) = \beta_i^2 - \rho \beta_i - \delta_i (\delta_i + \rho) + \gamma_i f_{c_i} = 0, \quad (\text{B.16})$$

where

$$\gamma_i = \frac{-1}{H_{c_i c_i}} ((2\delta_i + \rho) u_{c_i S_i} + f_{c_i}^i H_{S_i S_i}), \quad (\text{B.17})$$

and it leads to two eigenvalues

$$\beta_i^\pm = \frac{\rho}{2} \pm \sqrt{\left(\delta_i + \frac{\rho}{2}\right)^2 - \gamma_i f_{c_i}^i}. \quad (\text{B.18})$$

The optimal (i.e., convergent) path is governed by

$$x = k^+ e^{\beta_i^+ t} + k^- e^{\beta_i^- t} + x^* \text{ where } x_i = \begin{pmatrix} S_i \\ \lambda_i \end{pmatrix}, k^+ = \begin{pmatrix} k_1^+ \\ k_2^+ \end{pmatrix}, \text{ and } k^- = \begin{pmatrix} k_1^- \\ k_2^- \end{pmatrix}. \quad (\text{B.19})$$

k^+ and k^- are eigenvectors that each corresponds to β_i^+ and β_i^- , respectively, and that each solves $(M_i - I\beta_i^+)k^+ = 0$ and $(M_i - I\beta_i^-)k^- = 0$.

The concavity of H suggests

$$-\gamma_i > (2\delta_i + \rho) \left(\frac{u_{c_i} S_i}{H_{c_i c_i}} \right) + f_{c_i}^i \left(\frac{u_{c_i} S_i}{H_{c_i c_i}} \right)^2$$

which leads to

$$\left(\delta_i + \frac{\rho}{2} \right)^2 - \gamma_i f_{c_i}^i > \left(\delta_i + \frac{\rho}{2} + f_{c_i}^i \frac{u_{c_i} S_i}{H_{c_i c_i}} \right)^2 > 0. \quad (\text{B.20})$$

It shows that β_i^\pm is real. As β_i^\pm is symmetric around $\rho/2$, β_i^+ that exceeds $\rho/2$ can be ignored as it would violate the first transversality condition in (B.12): Otherwise, the habit with a positive value is left unused. A smaller eigenvalue, β_i^- , is either positive but smaller than $\rho/2$ (i.e., unstable) or negative (i.e., stable). Then the optimal path around the stationary point is determined by

$$S_i = k_1^- e^{\beta_i^- t} + S_i^* \quad \text{and} \quad \lambda_i = k_2^- e^{\beta_i^- t} + \lambda_i^*. \quad (\text{B.19}')$$

As substituting (B.19') into (B.14) and solving $(M_i - I\beta_i^-)k^- = 0$ for k^- lead to

$$\dot{c}_i = - \left(\frac{-u_{c_i} S_i}{H_{c_i c_i}} + \frac{f_{c_i}^i k_2^-}{H_{c_i c_i} k_1^-} \right) \dot{S}_i \quad \text{and} \quad \frac{k_2^-}{k_1^-} = \frac{(\delta_i + f_{c_i}^i u_{c_i} S_i / H_{c_i c_i} + \beta_i^-) H_{c_i c_i}}{-(f_{c_i}^i)^2},$$

respectively, I combine them together to obtain

$$\dot{c}_i = \left(\frac{\delta_i + \beta_i^-}{f_{c_i}^i} \right) \dot{S}_i. \quad (1.7)$$

Moreover, from (B.17) and

$$\delta_i + \beta_i^- = \left(\delta_i + \frac{\rho}{2} \right) - \sqrt{\left(\delta_i + \frac{\rho}{2} \right)^2 - \gamma_i f_{c_i}^i} \text{ where } \gamma_i = \frac{-1}{H_{c_i c_i}} \left((2\delta_i + \rho) u_{c_i S_i} + f_{c_i}^i H_{S_i S_i} \right),$$

it can be shown that

$$\text{sgn} \left(\frac{\delta_i + \beta_i^-}{f_{c_i}^i} \right) = \text{sgn}(\gamma_i) = \text{sgn} \left((2\delta_i + \rho) u_{c_i S_i} + f_{c_i}^i H_{S_i S_i} \right). \quad (1.8')$$

An individual is with adjacent complementarity when $((2\delta_i + \rho) u_{c_i S_i} + f_{c_i}^i H_{S_i S_i}) > 0$ and with distant complementarity when $((2\delta_i + \rho) u_{c_i S_i} + f_{c_i}^i H_{S_i S_i}) < 0$.

Model of Compulsive Addiction, á la Gruber and Köszegi (2001): The lifetime maximization problem in (1.11) subject to (1.13) suggests two kinds of maximizer (time-consistent and -inconsistent) whose system of intertemporal preference is either *stationary* or *nonstationary*. A nonstationary maximizer is also subdivided into a *naive* and *sophisticated* individual who is either not aware of or aware of conflict amongst selves over time. With no saving assumption and a time subscript denoting the period under the consideration, the Bellman equations can be specified.

$$V(S_t) = \begin{cases} \max_{a \in [0, y/p]} u(a_t, S_t) + v(c_t) + \left(\frac{1}{1+\rho} \right) V(S_{t+1}) & \text{if stationary, and} \\ \max_{a \in [0, y/p]} u(a_t, S_t) + v(c_t) + \left(\frac{\beta}{1+\rho} \right) V(S_{t+1}) & \text{if nonstationary} \end{cases} \quad (B.21)$$

The Euler equations of (B.21) characterize the consumption plan of each individual type at t . To obtain the Euler equation of a time-consistent individual, I first take the derivative of the stationary Bellman equation at t .

$$u_a(a_t, S_t) - p_t v'(c_t) = - \sum_{k=1}^{T-t} \left(\frac{1-\delta}{1+\rho} \right)^k \prod_{l=1}^{k-1} \left(1 + \frac{\partial a_{t+l}}{\partial S_{t+l}} \right) \times \\ \left((u_a(a_{t+k}, S_{t+k}) - p_{t+k} v'(c_{t+k})) \frac{\partial a_{t+k}}{\partial S_{t+k}} + u_S(a_{t+k}, S_{t+k}) \right) \quad (\text{B.22})$$

The derivative of the Bellman equation at $t+1$ as the part of plan at t is

$$u_a(a_{t+1}, S_{t+1}) - p_{t+1} v'(c_{t+1}) = - \sum_{k=2}^{T-t} \left(\frac{1-\delta}{1+\rho} \right)^{k-1} \prod_{l=2}^{k-1} \left(1 + \frac{\partial a_{t+l}}{\partial S_{t+l}} \right) \times \\ \left((u_a(a_{t+k}, S_{t+k}) - p_{t+k} v'(c_{t+k})) \frac{\partial a_{t+k}}{\partial S_{t+k}} + u_S(a_{t+k}, S_{t+k}) \right) \quad (\text{B.22}')$$

Multiplying $\left(\frac{1-\delta}{1+\rho} \right) \left(1 + \frac{\partial a_{t+1}}{\partial S_{t+1}} \right)$ to (B.22') and subtracting it from (B.22), I obtain

$$u_a(a_t, S_t) - p_t v'(c_t) = \left(\frac{1-\delta}{1+\rho} \right) (u_a(a_{t+1}, S_{t+1}) - p_{t+1} v'(c_{t+1}) - u_S(a_{t+1}, S_{t+1})) \quad (1.14)$$

which is the Euler equation of a time-consistent individual.

From a similar method, I may also obtain the Euler equations of naive and sophisticated individuals who are quasi-hyperbolic discounters. The Euler equation of a naive individual who is not aware of the future self-control problems is

$$u_a(a_t, S_t) - p_t v'(a_t) = \beta \left(\frac{1-\delta}{1+\rho} \right) (u_a(a_{t+1}^r, S_{t+1}) - p_{t+1} v'(c_{t+1}^r) - u_S(a_{t+1}^r, S_{t+1})) \quad (\text{B.23})$$

where the superscript r in RHS indicates that the consumption plan of a naive individual

at t is based on a false assumption that future selves from $t + 1$ and on are time-consistent. Although a bit more complicated, a similar method leads to the Euler equation of a sophisticated individual who is aware of the future self-control problem: However, note that unlike a naive individual, a sophisticated individual correctly anticipates that the self at $t + 1$ sets own optimality condition that is not a part of plan t . For any $t < T$

$$\begin{aligned}
u_a(a_t, S_t) - pv'(c_t) = & \\
& \left(\frac{1 - \delta}{1 + \rho} \right) \left(\left(1 + (1 - \beta) \frac{\partial a_{t+1}}{\partial S_{t+1}} \right) (u_a(a_{t+1}, S_{t+1}) - p_{t+1}v'(c_{t+1})) - \beta u_S(a_{t+1}, S_{t+1}) \right)
\end{aligned} \tag{1.15}$$

Although not included in Gruber and Köszegi (2001), an earlier version as the NBER working paper [p. 21] notes that the decomposition of (1.15) shows the strategic reaction and attempts to control against the future behavior by comparing to (B.23); the pessimism and incentive effects in O'Donoghue and Rabin (1999a, 2002) and an extra damage control effect as follows.

$$\begin{aligned}
u_a(a_t, S_t) - pv'(c_t) = & \beta \left(\frac{1 - \delta}{1 + \rho} \right) (u_a(a_{t+1}^r, S_{t+1}) - p_{t+1}v'(c_{t+1}^r) - u_S(a_{t+1}^r, S_{t+1})) \\
& + \beta \left(\frac{1 - \delta}{1 + \rho} \right) \left((u_a(a_{t+1}, S_{t+1}) - p_{t+1}v'(c_{t+1}) - u_S(a_{t+1}, S_{t+1})) \right. \\
& \quad \left. - (u_a(a_{t+1}^r, S_{t+1}) - p_{t+1}v'(c_{t+1}^r) - u_S(a_{t+1}^r, S_{t+1})) \right) \Bigg\} \text{pessimism effect} \\
& + (1 - \beta) \left(\frac{1 - \delta}{1 + \rho} \right) \frac{\partial a_{t+1}}{\partial S_{t+1}} (u_a(a_{t+1}, S_{t+1}) - p_{t+1}v'(c_{t+1})) \Bigg\} \text{incentive effect} \\
& + (1 - \beta) \left(\frac{1 - \delta}{1 + \rho} \right) (u_a(a_{t+1}, S_{t+1}) - p_{t+1}v'(c_{t+1})) \Bigg\} \text{damage control effect}
\end{aligned} \tag{B.24}$$

To understand the shift in the preferences between t_1 and t_2 with the change in consumption at τ , I first derive the discounted long-run marginal utility, $z(t)$. As reiterating

the Euler equation for a time-consistent individual in (1.14) leads to

$$u_a(a_t, S_t) - p_t v'(c_t) = \left(\frac{1-\delta}{1+\rho} \right)^{T-t} (u_a(a_T, S_T) - p_T v'(c_T)) - \sum_{k=1}^{T-t} \left(\frac{1-\delta}{1+\rho} \right)^k u_S(a_{t+k}, S_{t+k}), \quad (1.14')$$

I assume $T \rightarrow \infty$ and manipulate it to obtain a following optimal condition for a time-consistent individual.

$$z_r(t) = \left(\frac{1}{1+\rho} \right)^t u_a(a_t, S_t) + (1-\delta)^{-t} \sum_{k=t+1}^{\infty} \left(\frac{1-\delta}{1+\rho} \right)^k u_S(a_k, S_k) = \left(\frac{1}{1+\rho} \right)^t p_t v'(c_t) \quad (B.25)$$

where the term in RHS expresses the immediate and monetary cost of a .

Taking the derivative of $z_r(t)$ for $\tau > t$ leads to

$$\begin{aligned} z'_r(t, \tau) &= (1-\delta)^{-t} \left(\frac{1-\delta}{1+\rho} \right)^\tau u_{aS}(a_\tau, S_\tau) \\ &+ (1-\delta)^{-t} \sum_{k=\tau+1}^{\infty} \left(\frac{1-\delta}{1+\rho} \right)^k (1-\delta)^{k-\tau} \prod_{l=\tau+1}^{k-1} \left(1 + \frac{\partial a_l}{\partial S_l} \right) \left(u_{aS}(a_k, S_k) \frac{\partial a_k}{\partial S_k} + u_{SS}(a_k, S_k) \right) \end{aligned} \quad (B.26)$$

Yet, as substituting (B.25) and (B.26) into (1.16) leads to an expression that is too complex to economic-meaningfully evaluate, I examine it along a constant consumption path where p_t , a_t , and S_t are constant for all t . It implies $a_t = (\delta/(1-\delta)) S_t$ and the derivatives everywhere in (1.16) are also constant. With such assumptions in mind, I first convert

(B.25) and (B.26) into their continuous forms,

$$z_r(t) = e^{-\rho t} \left(u_a + \frac{u_S}{\delta + \rho} \right), \quad (\text{B.25}')$$

$$z'_r(t, \tau) = e^{\delta t - (\delta + \rho)\tau} \left(\frac{(2\delta + \rho)u_{aS} + (1 - \delta)u_{SS}}{\delta + \rho} \right). \quad (\text{B.26}')$$

and substitute (B.25') and (B.26') into (1.16) to obtain

$$R'_r(t_1, t_2; \tau) = \left(\frac{(2\delta + \rho)u_{aS} + (1 - \delta)u_{SS}}{(\delta + \rho)u_a + u_S} \right) e^{\rho(t_2 - t_1)} (\alpha(\tau - t_1) - \alpha(\tau - t_2)) \quad (\text{B.27})$$

where

$$t_2 > t_1 \text{ and } \alpha(\tau - t) = \begin{cases} e^{-(\delta + \rho)(\tau - t)} & \text{for } \tau - t > 0, \\ e^{\delta(\tau - t)} & \text{for } \tau - t < 0. \end{cases}$$

(B.27), for example, indicates that for the change in consumption at τ ,

$$\text{sgn}(R'_r(t_1, t_2; \tau)) = \begin{cases} \text{sgn}((2\delta + \rho)u_{aS} + (1 - \delta)u_{SS}) & \text{for } \tau < \frac{(\delta + \rho)t_1 + \delta t_2}{2\delta + \rho}, \\ \text{sgn}(-(2\delta + \rho)u_{aS} - (1 - \delta)u_{SS}) & \text{for } \tau > \frac{(\delta + \rho)t_1 + \delta t_2}{2\delta + \rho}. \end{cases} \quad (\text{B.28})$$

Thus, for a time-consistent individual, there is the complementarity between adjacent periods (i.e., between t_1 and $\tau < ((\delta + \rho)t_1 + \delta t_2)/(2\delta + \rho)$ and between t_2 and $\tau > ((\delta + \rho)t_1 + \delta t_2)/(2\delta + \rho)$) when

$$(2\delta + \rho)u_{aS} + (1 - \delta)u_{SS} > 0. \quad (1.17)$$

Moreover, it can be verified that (1.17) is also the condition of adjacent complementarity for a naive individual. The difference is an extra discount factor of β in $z_n(t)$ and $z'_n(t)$ such

that

$$z_n(t) = e^{-\rho t} \left(u_a + \frac{\beta u_S}{\delta + \rho} \right), \quad (\text{B.29})$$

$$z'_n(t, \tau) = e^{\delta t - (\delta + \rho)\tau} \beta \left(\frac{(2\delta + \rho)u_{aS} + (1 - \delta)u_{SS}}{\delta + \rho} \right). \quad (\text{B.30})$$

I use same method to find the condition of adjacent complementarity for a sophisticated individual. Again, after reiterating the Euler equation for a sophisticated individual in (1.15), I manipulate it to obtain

$$z_s(t) = \left(\frac{1}{1 + \rho} \right)^t u_a(a_t, S_t) + \beta(1 - \delta)^{-t} \sum_{k=t+1}^{\infty} \left(\frac{1 - \delta}{1 + \rho} \right)^k \prod_{l=t+1}^{k-1} \left(1 + (1 - \beta) \frac{\partial a_l}{\partial S_l} \right) u_S(a_k, S_k), \quad (\text{B.31})$$

of which the derivative for $\tau > t$ is

$$\begin{aligned} z'_s(t, \tau) &= \beta(1 - \delta)^{-t} \left(\frac{1 - \delta}{1 + \rho} \right)^{\tau} \prod_{l=t+1}^{\tau-1} \left(1 + (1 - \beta) \frac{\partial a_l}{\partial S_l} \right) u_{aS}(a_{\tau}, S_{\tau}) \\ &+ \beta(1 - \delta)^{-t} \left(\sum_{k=\tau+1}^{\infty} \left(\frac{1 - \delta}{1 + \rho} \right)^k \left(\frac{\partial}{\partial a_{\tau}} \prod_{l=t+1}^{k-1} \left(1 + (1 - \beta) \frac{\partial a_l}{\partial S_l} \right) \right) u_S(a_k, S_k) \right. \\ &\quad \left. + \sum_{k=\tau+1}^{\infty} \left(\frac{1 - \delta}{1 + \rho} \right)^k \prod_{l=t+1}^{k-1} \left(1 + (1 - \beta) \frac{\partial a_l}{\partial S_l} \right) \times \right. \\ &\quad \left. (1 - \delta)^{k-\tau} \prod_{l=\tau+1}^{k-1} \left(1 + \frac{\partial a_l}{\partial S_l} \right) \left(u_{aS}(a_k, S_k) \frac{\partial a_k}{\partial S_k} + u_{SS}(a_k, S_k) \right) \right). \end{aligned} \quad (\text{B.32})$$

$R'_s(t_1, t_2; \tau)$ or (1.16), after substituting (B.31) and (B.32), becomes even more complicated to be evaluated, and I again examine it along the constant consumption path.

After converting into their continuous forms, I have

$$z_s(t) = e^{-\rho t} \left(u_a + e^{(1-\beta)\delta t} \left(\frac{\beta(1-\delta)}{1-\beta\delta} \right) \left(\frac{u_S}{\beta\delta + \rho} \right) \right), \quad (\text{B.31}')$$

$$z'_s(t, \tau) = e^{\delta t - (\beta\delta + \rho)\tau} \left(\frac{\beta(1-\delta)}{1-\beta\delta} \right) \left(\frac{((1+\beta)\delta + \rho) u_{aS} + (1-\delta)u_{SS}}{\beta\delta + \rho} \right), \quad (\text{B.32}')$$

and the constant consumption path also suggests that for $t_1 \leq \underline{t} \leq t_2$, $q(a_{t_1}) \approx q(a_{\underline{t}}) \approx q(a_{t_2})$ where

$$q(a_t) = u_a + e^{(1-\beta)\delta t} \left(\frac{\beta(1-\delta)}{1-\beta\delta} \right) \left(\frac{u_S}{\beta\delta + \rho} \right).$$

Also note that $q(a_{t_1}) \approx q(a_{\underline{t}}) \approx q(a_{t_2})$ holds when t is relatively small, which is an assumption made in Gruber and Köszegi (2001, p. 1283) for the convergence solution that is “far from the end of horizon.” With such assumptions, I now substitute (B.31') and (B.32') into (1.16) to obtain

$$R'_s(t_1, t_2; \tau) = \left(\frac{\beta(1-\delta)}{1-\beta\delta} \right) \left(\frac{((1+\beta)\delta + \rho) u_{aS} + (1-\delta)u_{SS}}{(1-\beta\delta)(\beta\delta + \rho)u_a + e^{(1-\beta)\delta \underline{t}} \beta(1-\delta)u_S} \right) \times \\ e^{\rho(t_2 - t_1)} (\alpha(\tau - t_1) - \alpha(\tau - t_2)) \quad (\text{B.33})$$

where

$$t_2 > t_1 \text{ and } \alpha(\tau - t) = \begin{cases} e^{-(\beta\delta + \rho)\tau + (\delta + \rho)t} & \text{for } \tau - t > 0, \\ e^{\delta(\tau - \beta t)} & \text{for } \tau - t < 0. \end{cases}$$

(B.33), for example, indicates that for the change in consumption at τ ,

$$\text{sgn} (R'_s(t_1, t_2; \tau)) = \begin{cases} \text{sgn} (((1 + \beta)\delta + \rho) u_{aS} + (1 - \delta)u_{SS}) & \text{for } \tau < \frac{((\delta + \rho)t_1 + \beta\delta t_2)}{((1 + \beta)\delta + \rho)}, \\ \text{sgn} (-((1 + \beta)\delta + \rho) u_{aS} - (1 - \delta)u_{SS}) & \text{for } \tau > \frac{((\delta + \rho)t_1 + \beta\delta t_2)}{((1 + \beta)\delta + \rho)}. \end{cases} \quad (\text{B.34})$$

Thus, for a sophisticated individual, there is the complementarity between adjacent periods (i.e., between t_1 and $\tau < ((\delta + \rho)t_1 + \beta\delta t_2)/((1 + \beta)\delta + \rho)$ and between t_2 and $\tau > ((\delta + \rho)t_1 + \beta\delta t_2)/((1 + \beta)\delta + \rho)$) when

$$((1 + \beta)\delta + \rho) u_{aS} + (1 - \delta)u_{SS} > 0. \quad (1.18)$$

A Simple Model of Myopic Addiction: I develop a simple model of myopic addiction. An individual is called *myopic* about the habit-formation when the stock of habit is considered to be constant over time, $\dot{S} = 0$, although it may actually evolve according to the first in (1.13). If a time subscript denotes the period under the consideration as before, the Bellman equation for a myopic individual is, then,

$$V(S_t) = \max_{a \in [0, y/p]} u(a_t, S_t) + v(c_t) + \left(\frac{1}{1 + \rho} \right) V(S_{t+1}^*) \quad (\text{B.35})$$

where $S_{t+1}^* = S_t$. More generally, an individual may be *quasi-myopic* and behave strategically by learning about the change in the stock of habit induced by consumption. For the simplicity, I do not explore the learning process, but examine a particular quasi-myopic individual with a partial understanding about the change in the stock of habit (a η -portion of the change): That is, a quasi-myopic individual is in the middle of strategical learning

process such that momentarily the change in the stock of habit is governed by

$$S^\circ(t+1) = \eta(1-\delta)a(t) + (1-\eta\delta)S(t). \quad (1.22)$$

Then, the Bellman equation of a quasi-myopic individual can be specified as

$$V(S_t) = \max_{a \in [0, y/p]} u(a_t, S_t) + v(c_t) + \left(\frac{1}{1+\rho}\right) V(S_{t+1}^\circ) \quad (B.36)$$

The Euler equations of (B.36) characterize the consumption plan of a quasi-myopic individual type at t . Taking the derivative of the quasi-myopic Bellman equation at t ,

$$\begin{aligned} u_a(a_t, S_t) - p_t v'(c_t) &= -\eta(1-\delta) \sum_{k=1}^{\infty} \left(\frac{1}{1+\rho}\right)^k \prod_{l=1}^{k-1} \left((1-\eta\delta) + \eta(1-\delta) \frac{\partial a_{t+l}}{\partial S_{t+l}^\circ} \right) \times \\ &\quad \left((u_a(a_{t+k}, S_{t+k}^\circ) - p_{t+k} v'(c_{t+k})) \frac{\partial a_{t+k}}{\partial S_{t+k}^\circ} + u_S(a_{t+k}, S_{t+k}^\circ) \right) \end{aligned} \quad (B.37)$$

The derivative of the Bellman equation at $t+1$ as the part of plan at t is

$$\begin{aligned} u_a(a_{t+1}, S_{t+1}^\circ) - p_{t+1} v'(c_{t+1}) &= -\eta(1-\delta) \sum_{k=2}^{\infty} \left(\frac{1}{1+\rho}\right)^{k-1} \prod_{l=2}^{k-1} \left((1-\eta\delta) + \eta(1-\delta) \frac{\partial a_{t+l}}{\partial S_{t+l}^\circ} \right) \times \\ &\quad \left((u_a(a_{t+k}, S_{t+k}^\circ) - p_{t+k} v'(c_{t+k})) \frac{\partial a_{t+k}}{\partial S_{t+k}^\circ} + u_S(a_{t+k}, S_{t+k}^\circ) \right) \end{aligned} \quad (B.37')$$

Multiplying $\left(\frac{1}{1+\rho}\right) \left((1-\eta\delta) + \eta(1-\delta) \frac{\partial a_{t+1}}{\partial S_{t+1}^\circ} \right)$ to (B.37') and subtracting it from (B.37), I

obtain

$$u_a(a_t, S_t) - p_t v'(c_t) = \left(\frac{1 - \eta\delta}{1 + \rho} \right) (u_a(a_{t+1}, S_{t+1}^\circ) - p_{t+1} v'(c_{t+1})) - \eta \left(\frac{1 - \delta}{1 + \rho} \right) u_S(a_{t+1}, S_{t+1}^\circ) \quad (1.23)$$

which is the Euler equation of a quasi-myopic individual.

Same method for a sophisticated individual, the reiteration of the Euler equation in (1.23) and manipulation, leads to the long-run marginal utility

$$z_q(t) = \left(\frac{1}{1 + \rho} \right)^t u_a(a_t, S_t^\circ) + (1 - \eta\delta)^{-t} \left(\frac{\eta(1 - \delta)}{1 - \eta\delta} \right) \sum_{k=t+1}^T \left(\frac{1 - \eta\delta}{1 + \rho} \right)^k u_S(a_k, S_k^\circ), \quad (B.38)$$

of which derivative for $\tau > t$ is

$$\begin{aligned} z'_q(t; \tau) &= (1 - \eta\delta)^{-t} \left(\frac{\eta(1 - \delta)}{1 - \eta\delta} \right) \left(\frac{1 - \eta\delta}{1 + \rho} \right)^\tau u_{aS}(a_\tau, S_\tau^\circ) + (1 - \eta\delta)^{-t} \left(\frac{\eta(1 - \delta)}{1 - \eta\delta} \right) \eta(1 - \delta) \times \\ &\quad \sum_{k=\tau+1}^{\infty} \left(\frac{1 - \eta\delta}{1 + \rho} \right)^k \prod_{l=\tau+1}^{k-1} \left((1 - \eta\delta) + \eta(1 - \delta) \frac{\partial a_l}{\partial S_l^\circ} \right) \left(u_{aS}(a_k, S_k^\circ) \frac{\partial a_k}{\partial S_k^\circ} + u_{SS}(a_k, S_k^\circ) \right). \end{aligned} \quad (B.39)$$

I, again, examine it along the constant consumption path. Then, their continuous forms are

$$z_q(t) = e^{-\rho t} \left(u_a + \left(\frac{\eta(1 - \delta)}{1 - \eta\delta} \right) \left(\frac{u_S}{\eta\delta + \rho} \right) \right) \quad (B.38')$$

$$z'_q(t) = e^{\eta\delta t - (\eta\delta + \rho)\tau} \left(\frac{\eta(1 - \delta)}{1 - \eta\delta} \right) \left(\frac{(2\eta\delta + \rho)u_{aS} + \eta(1 - \delta)u_{SS}}{\eta\delta + \rho} \right) \quad (B.39')$$

which are substituted into (1.16).

$$R'(t_1, t_2; \tau) = \left(\frac{\eta(1-\delta)}{1-\eta\delta} \right) \left(\frac{(2\eta\delta + \rho)u_{aS} + \eta(1-\delta)u_{SS}}{(1-\eta\delta)(\eta\delta + \rho)u_a + \eta(1-\delta)u_S} \right) \times e^{\rho(t_2-t_1)} (\alpha(\tau - t_1) - \alpha(\tau - t_2)) \quad (\text{B.40})$$

where

$$t_2 > t_1 \text{ and } \alpha(\tau - t) = \begin{cases} e^{-(\eta\delta+\rho)(\tau-t)} & \text{for } \tau - t > 0, \\ e^{\eta\delta(\tau-t)} & \text{for } \tau - t < 0. \end{cases}$$

(B.40) indicates that for the change in consumption at τ ,

$$\text{sgn}(R'_q(t_1, t_2; \tau)) = \begin{cases} \text{sgn}((2\eta\delta + \rho)u_{aS} + \eta(1-\delta)u_{SS}) & \text{for } \tau < \frac{(\eta\delta+\rho)t_1 + \eta\delta t_2}{2\eta\delta + \rho} \\ \text{sgn}(-(2\eta\delta + \rho)u_{aS} - \eta(1-\delta)u_{SS}) & \text{for } \tau > \frac{(\eta\delta+\rho)t_1 + \eta\delta t_2}{2\eta\delta + \rho} \end{cases} \quad (\text{B.41})$$

For a quasi-myopic individual, there is the complementarity between adjacent periods (i.e., between t_1 and $\tau < ((\eta\delta + \rho)t_1 + \eta\delta t_2) / (2\eta\delta + \rho)$ and between t_2 and $\tau > ((\eta\delta + \rho)t_1 + \eta\delta t_2) / (2\eta\delta + \rho)$) when

$$(2\eta\delta + \rho)u_{aS} + \eta(1-\delta)u_{SS} > 0. \quad (1.24)$$

Furthermore, for a myopic individual who considers the stock of habit is constant over time ($S_{t+1}^* = S_t$ or $\eta = 0$), there is adjacent complementarity when

$$u_{aS} > 0. \quad (1.21)$$

Appendix C: For Multiple Habits and Addictions

C.1 Mathematical Derivation

Derivation of New Equation of Motion, $\dot{\Gamma}$: The optimal control problem that an individual tries to solve, suggested by (2.1)-(2.4) with M.1-M.4, is a problem containing the inequality integral constraint (2.3) (Chiang, 1992). To solve such a problem, I need introduce a new state variable Γ where (2.3) and its boundary condition are replaced in terms of Γ . Define a new state variable

$$\Gamma(t) = - \int_0^t p(t)c(t)e^{-rt} dt + \int_0^t w(S(t))e^{-rt} dt. \quad (\text{C.1})$$

Then, the equation of motion for Γ , which is the derivative of (C.1) with respect to time, is

$$\dot{\Gamma} = -p(t)c(t)e^{-rt} + w(S(t))e^{-rt}. \quad (\text{C.2})$$

The initial and terminal values defining the boundary conditions of (C.2) are

$$\begin{aligned} \Gamma(0) &= - \int_0^0 p(t)c(t)e^{-rt} dt + \int_0^0 w(S(t))e^{-rt} dt = 0, \\ \Gamma(T) &= - \int_0^T p(t)c(t)e^{-rt} dt + \int_0^T w(S(t))e^{-rt} dt \geq -A_0. \end{aligned} \quad (\text{C.3})$$

(C.2) replaces (2.3). Along with the boundary conditions (C.3), (C.2) is to construct the current-valued Hamiltonian (2.7).

Derivation of Shadow Price, Eq. (2.13): I first express (2.9) in an algebraic form

$$\dot{\lambda}_i = -u_{S_i} + \lambda_i(\rho + \delta_i) - \mu w_{S_i} e^{-rt}. \quad (\text{C.4})$$

(C.4) specifies the change in λ_i . Moving the middle term in RHS to LHS, multiplying $e^{-(\rho+\delta_i)t}$, and integrating with respect to τ from t and to T , I have

$$\begin{aligned} \int_t^T e^{-(\rho+\delta_i)(\tau-t)} (\dot{\lambda}_i - \lambda_i(\rho + \delta_i)) d\tau &= \left[e^{-(\rho+\delta_i)(\tau-t)} \lambda_i \right]_t^T \\ &= -\lambda_i = - \int_t^T e^{-(\rho+\delta_i)(\tau-t)} u_{S_i} d\tau - \int_t^T \mu e^{-(\rho+r+\delta_i)(\tau-t)} w_{S_i} d\tau. \end{aligned} \quad (\text{C.5})$$

It is now straightforward that the shadow (i.e. future) price associated with each habit accumulated by current c_i is described by (2.13).

Derivation of General Solution, Eq. (2.20): If I let $\bar{\beta}$ be a diagonal matrix with β_i^- , (2.19) can be rearranged

$$H_{\lambda S}^* s + H_{\lambda \lambda}^* l = s \bar{\beta} \quad \text{and} \quad -H_{SS}^* s + (\rho I - H_{S\lambda}^*) l = l \bar{\beta}. \quad (\text{C.6})$$

(C.6) can be solved for non-zero s and l , and combining (C.6) together, it is clear that such a s has to satisfy (2.21). Moreover, substituting (2.18') and (C.6) to (2.14) and then simplifying, I can derive

$$\begin{aligned} \dot{c} &= -u_{cc}^{-1} (u_{cS} \alpha^{\text{tr}} l s^{-1}) \dot{S} \\ &= -u_{cc}^{-1} (u_{cS} + \alpha^{\text{tr}} (H_{\lambda \lambda}^{*-1} s \bar{\beta} s^{-1} - H_{\lambda \lambda}^{*-1} H_{\lambda S}^*)) \dot{S} \\ &= \alpha^{-1} (s \bar{\beta} s^{-1} + \delta) \dot{S}, \end{aligned} \quad (\text{C.7})$$

which gives (2.20).

Derivation of Characteristic Polynomial and Roots When $n = m = 2$, Eq. (2.17')

and (2.22): Since $n = m = 2$ and if (2.14) is solved for c_i ,

$$\begin{aligned} \dot{c}_i &= \frac{\begin{vmatrix} u_{c_i c_j} & u_{c_j c_j} \\ u_{c_i S_i} & u_{c_j S_i} \end{vmatrix}}{\begin{vmatrix} u_{c_i c_i} & u_{c_i c_j} \\ u_{c_i c_j} & u_{c_j c_j} \end{vmatrix}} \dot{S}_i + \frac{\begin{vmatrix} u_{c_i c_j} & u_{c_j c_j} \\ u_{c_i S_j} & u_{c_j S_j} \end{vmatrix}}{\begin{vmatrix} u_{c_i c_i} & u_{c_i c_j} \\ u_{c_i c_j} & u_{c_j c_j} \end{vmatrix}} \dot{S}_j + \frac{\begin{vmatrix} u_{c_i c_j} & u_{c_j c_j} \\ \alpha_{ii} & \alpha_{ij} \end{vmatrix}}{\begin{vmatrix} u_{c_i c_i} & u_{c_i c_j} \\ u_{c_i c_j} & u_{c_j c_j} \end{vmatrix}} \dot{\lambda}_i + \frac{\begin{vmatrix} u_{c_i c_j} & u_{c_j c_j} \\ \alpha_{ji} & \alpha_{jj} \end{vmatrix}}{\begin{vmatrix} u_{c_i c_i} & u_{c_i c_j} \\ u_{c_i c_j} & u_{c_j c_j} \end{vmatrix}} \dot{\lambda}_j \\ &= \frac{\theta_{ii}}{|u_{cc}|} \dot{S}_i + \frac{\theta_{ij}}{|u_{cc}|} \dot{S}_j + \frac{\chi_{ii}}{|u_{cc}|} \dot{\lambda}_i + \frac{\chi_{ij}}{|u_{cc}|} \dot{\lambda}_j. \end{aligned} \quad (\text{C.8})$$

As long as the transversality condition of Γ in (2.11) is met and μ is a nonnegative constant is kept in track, $\dot{\Gamma}$ and $\dot{\mu}$ may be omitted at no loss from the motion of system (Chiang, 1992, p.284). The linear approximation to (2.6) and (2.9), using (C.8), yields the system with M that can be specified as

$$\left(\begin{array}{cc} -\delta_1 + \alpha_{11} \frac{\theta_{11}}{|u_{cc}|} + \alpha_{12} \frac{\theta_{21}}{|u_{cc}|} & \alpha_{11} \frac{\theta_{12}}{|u_{cc}|} + \alpha_{12} \frac{\theta_{22}}{|u_{cc}|} \\ \alpha_{21} \frac{\theta_{11}}{|u_{cc}|} + \alpha_{22} \frac{\theta_{21}}{|u_{cc}|} & -\delta_2 + \alpha_{21} \frac{\theta_{12}}{|u_{cc}|} + \alpha_{22} \frac{\theta_{22}}{|u_{cc}|} \\ -HS_1 S_1 - u_{c_1 S_1} \frac{\theta_{11}}{|u_{cc}|} - u_{c_2 S_1} \frac{\theta_{21}}{|u_{cc}|} & -HS_1 S_2 - u_{c_1 S_1} \frac{\theta_{12}}{|u_{cc}|} - u_{c_2 S_1} \frac{\theta_{22}}{|u_{cc}|} \\ -HS_1 S_2 - u_{c_1 S_2} \frac{\theta_{11}}{|u_{cc}|} - u_{c_2 S_2} \frac{\theta_{21}}{|u_{cc}|} & -HS_2 S_2 - u_{c_1 S_2} \frac{\theta_{12}}{|u_{cc}|} - u_{c_2 S_2} \frac{\theta_{22}}{|u_{cc}|} \\ \\ \alpha_{11} \frac{\chi_{11}}{|u_{cc}|} + \alpha_{12} \frac{\chi_{21}}{|u_{cc}|} & \alpha_{11} \frac{\chi_{12}}{|u_{cc}|} + \alpha_{12} \frac{\chi_{22}}{|u_{cc}|} \\ \alpha_{21} \frac{\chi_{11}}{|u_{cc}|} + \alpha_{22} \frac{\chi_{21}}{|u_{cc}|} & \alpha_{21} \frac{\chi_{12}}{|u_{cc}|} + \alpha_{22} \frac{\chi_{22}}{|u_{cc}|} \\ \rho + \delta_1 - u_{c_1 S_1} \frac{\chi_{11}}{|u_{cc}|} - u_{c_2 S_1} \frac{\chi_{21}}{|u_{cc}|} & -u_{c_1 S_1} \frac{\chi_{12}}{|u_{cc}|} - u_{c_2 S_1} \frac{\chi_{22}}{|u_{cc}|} \\ -u_{c_1 S_2} \frac{\chi_{11}}{|u_{cc}|} - u_{c_2 S_2} \frac{\chi_{21}}{|u_{cc}|} & \rho + \delta_2 - u_{c_1 S_2} \frac{\chi_{12}}{|u_{cc}|} - u_{c_2 S_2} \frac{\chi_{22}}{|u_{cc}|} \end{array} \right). \quad (\text{C.9})$$

Moreover, the elements in (C.9) have following relations.

$$\begin{aligned}\alpha_{ii} \frac{\theta_{ii}}{|u_{cc}|} + \alpha_{ij} \frac{\theta_{ji}}{|u_{cc}|} &= u_{c_i S_i} \frac{\chi_{ii}}{|u_{cc}|} + u_{c_j S_i} \frac{\chi_{ji}}{|u_{cc}|} & \alpha_{ii} \frac{\theta_{ij}}{|u_{cc}|} + \alpha_{ij} \frac{\theta_{jj}}{|u_{cc}|} &= u_{c_i S_j} \frac{\chi_{ii}}{|u_{cc}|} + u_{c_j S_j} \frac{\chi_{ji}}{|u_{cc}|} \\ \alpha_{ii} \frac{\chi_{ij}}{|u_{cc}|} + \alpha_{ij} \frac{\chi_{jj}}{|u_{cc}|} &= \alpha_{ji} \frac{\chi_{ii}}{|u_{cc}|} + \alpha_{jj} \frac{\chi_{ji}}{|u_{cc}|} & u_{c_i S_i} \frac{\theta_{ij}}{|u_{cc}|} + u_{c_j S_i} \frac{\theta_{jj}}{|u_{cc}|} &= u_{c_i S_j} \frac{\theta_{ii}}{|u_{cc}|} + u_{c_j S_j} \frac{\theta_{ji}}{|u_{cc}|}\end{aligned}$$

which shows the symmetry among the elements in (C.9). Given the the relation among elements of M , the sum of all n^{th} order cofactors in M can be specified as follows.

$$C_1 = \text{tr}(J) = 2\rho,$$

$$\begin{aligned}C_2 &= \frac{\partial^2 \det(J)}{\partial j_{11} \partial j_{22}} + \frac{\partial^2 \det(J)}{\partial j_{11} \partial j_{33}} + \frac{\partial^2 \det(J)}{\partial j_{11} \partial j_{44}} + \frac{\partial^2 \det(J)}{\partial j_{22} \partial j_{33}} + \frac{\partial^2 \det(J)}{\partial j_{22} \partial j_{44}} + \frac{\partial^2 \det(J)}{\partial j_{33} \partial j_{44}} \\ &= \rho^2 + j_{11}(\rho - j_{11}) + j_{22}(\rho - j_{22}) - 2(j_{12}j_{21} + j_{14}j_{32}) - (j_{13}j_{31} + j_{24}j_{42}),\end{aligned}\quad (\text{C.10})$$

$$\begin{aligned}C_3 &= \frac{\partial \det(J)}{\partial j_{11}} + \frac{\partial \det(J)}{\partial j_{22}} + \frac{\partial \det(J)}{\partial j_{33}} + \frac{\partial \det(J)}{\partial j_{44}} \\ &= \rho(j_{11}(\rho - j_{11}) + j_{22}(\rho - j_{22}) - 2(j_{12}j_{21} + j_{14}j_{32}) - (j_{13}j_{31} + j_{24}j_{42})).\end{aligned}$$

where j_{ij} is the element of M . Using (C.10), it is straightforward to derive the characteristic polynomial of the 4th degree (2.17'), and C_n have the relation such that $-\rho^3 + \rho C_2 - C_3 = 0$. Letting $K = C_2 - \rho^2$, the Ferrari's method on the quartic equation leads to four characteristic roots (2.22).

Derivation of Solution When $n = m = 2$, Eq. (2.20'): As $n = m = 2$ and s can be normalized,

$$\alpha = \begin{pmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{pmatrix}, \quad s = \begin{pmatrix} \frac{s_{11}}{s_{21}} & 1 \\ 1 & \frac{s_{22}}{s_{12}} \end{pmatrix}, \quad e^{\bar{\beta}t} = \begin{pmatrix} e^{\beta_1 t} \\ e^{\beta_2 t} \end{pmatrix}, \quad \text{and} \quad \bar{\beta} = \begin{pmatrix} \beta_1 & 0 \\ 0 & \beta_2 \end{pmatrix}.$$

For the simplicity, I may restrict that how each c_i relate to both S is symmetric. It implies that φ is a symmetric matrix and that

$$\varphi = s\bar{\beta}s^{-1} \quad (\text{C.11})$$

By solving (C.11) for φ and s , I arrive at the coefficient in (2.20').

Using the element in (C.9) and as the cross effect among habits are zero, it is tedious but straightforward that

$$\begin{aligned} K &= -\gamma_1 - \gamma_2 + \alpha_{11}A_{11} + \alpha_{12}A_{21} + \alpha_{21}A_{12} + \alpha_{22}A_{22} \\ \det(J) &= \gamma_1\gamma_2 - \gamma_2(\alpha_{11}A_{11} + \alpha_{12}A_{21}) - \gamma_1(\alpha_{21}A_{12} + \alpha_{22}A_{22}) \end{aligned} \quad (\text{C.12})$$

with $\gamma_i = \delta_i(\delta_i + \rho)$

$$A_{ii} = \frac{1}{|u_{cc}|} ((2\delta_i + \rho)\theta_{ii} + H_{S_i S_i} \chi_{ii}) \quad A_{ij} = \frac{1}{|u_{cc}|} ((2\delta_j + \rho)\theta_{ij} + H_{S_j S_j} \chi_{ij})$$

Using the element of K and $\det(J)$, I know

$$\begin{aligned} \left(\frac{\rho}{2}\right)^2 - \frac{K}{2} &= \left(\delta_1 + \frac{\rho}{2}\right)^2 - \left(\frac{\gamma_1 - \gamma_2 + \alpha_{11}A_{11} + \alpha_{12}A_{21} + \alpha_{21}A_{12} + \alpha_{22}A_{22}}{2}\right) \\ &= \left(\delta_2 + \frac{\rho}{2}\right)^2 - \left(\frac{\gamma_2 - \gamma_1 + \alpha_{11}A_{11} + \alpha_{12}A_{21} + \alpha_{21}A_{12} + \alpha_{22}A_{22}}{2}\right) \end{aligned} \quad (\text{C.13})$$

and

$$\begin{aligned}
K^2 - 4 \det(J) &= (\gamma_1 - \gamma_2 + \alpha_{11}A_{11} + \alpha_{12}A_{21} + \alpha_{21}A_{12} + \alpha_{22}A_{22})^2 - 4(\alpha_{11}A_{11} + \alpha_{12}A_{21})(\gamma_1 - \gamma_2) \\
&= (\gamma_2 - \gamma_1 + \alpha_{11}A_{11} + \alpha_{12}A_{21} + \alpha_{21}A_{12} + \alpha_{22}A_{22})^2 + 4(\alpha_{21}A_{12} + \alpha_{22}A_{22})(\gamma_1 - \gamma_2)
\end{aligned} \tag{C.14}$$

Letting $\eta_{ii} = \gamma_i - \gamma_j + \alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} + \alpha_{ji}A_{ij} + \alpha_{jj}A_{jj}$, I can rearrange the sum of the roots and a depreciation rate

$$\delta_i + \beta_i = \delta_i + \frac{\rho}{2} - \sqrt{\left(\delta_i + \frac{\rho}{2}\right)^2 - \left(\frac{\eta_{ii} - \sqrt{\eta_{ii}^2 - 4(\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji})(\gamma_i - \gamma_j)}}{2}\right)}. \tag{C.15}$$

$\beta_i + \delta_i > 0$ when $\eta_{ii}, \alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$. Also $\beta_i + \delta_i < 0$ when $\eta_{ii} > 0$ but $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} < 0$ or when $\eta_{ii} < 0$. Similarly

$$\delta_i + \beta_j = \delta_i + \frac{\rho}{2} - \sqrt{\left(\delta_i + \frac{\rho}{2}\right)^2 - \left(\frac{\eta_{ii} + \sqrt{\eta_{ii}^2 - 4(\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji})(\gamma_i - \gamma_j)}}{2}\right)}. \tag{C.16}$$

$\beta_j + \delta_i > 0$ when $\eta_{ii}, \alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} < 0$ or when $\eta_{ii} > 0$. $\beta_j + \delta_i < 0$ when $\eta_{ii} < 0$ but $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$. Thus, both, $\beta_i + \delta_i$ and $\beta_j + \delta_i$, are positive if $\eta_{ii} > 0$ and $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$. And both are negative when $\eta_{ii} < 0$ and $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$. It implies that $\text{sgn}(\beta_i + \delta_i) = \text{sgn}(\beta_j + \delta_i)$ if $\alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} > 0$.

A similar result can be noted for the other depreciation rate. Letting $\eta_{ij} = \gamma_j - \gamma_i + \alpha_{ii}A_{ii} + \alpha_{ij}A_{ji} + \alpha_{ji}A_{ij} + \alpha_{jj}A_{jj}$,

$$\delta_j + \beta_i = \delta_j + \frac{\rho}{2} - \sqrt{\left(\delta_j + \frac{\rho}{2}\right)^2 - \left(\frac{\eta_{ij} - \sqrt{\eta_{ij}^2 + 4(\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj})(\gamma_i - \gamma_j)}}{2}\right)} \tag{C.17}$$

$\beta_i + \delta_j > 0$ when $\eta_{ij} > 0$ but $\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} < 0$. $\beta_i + \delta_j < 0$ when $\eta_{ij}, \alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$ or when $\eta_{ij} < 0$. Similarly

$$\delta_j + \beta_j = \delta_i + \frac{\rho}{2} - \sqrt{\left(\delta_i + \frac{\rho}{2}\right)^2 - \left(\frac{\eta_{ij} + \sqrt{\eta_{ij}^2 + 4(\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj})(\gamma_i - \gamma_j)}}{2}\right)}. \quad (\text{C.18})$$

$\beta_j + \delta_j > 0$ when $\eta_{ij} < 0$ but $\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$ or when $\eta_{ij} > 0$. $\beta_j + \delta_j < 0$ when $\eta_{ij}, \alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} < 0$. While $\beta_i + \delta_j > 0$ and $\beta_j + \delta_j < 0$ at the same time cannot take place, $\beta_i + \delta_j < 0$ and $\beta_j + \delta_j > 0$ if $\eta_{ij}, \alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$ or if $\eta_{ij} < 0$ but $\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$. It implies that $\text{sgn}(\beta_i + \delta_j) \neq \text{sgn}(\beta_j + \delta_j)$ if $\alpha_{ji}A_{ij} + \alpha_{jj}A_{jj} > 0$. Thus, I arrive at (2.26).

Appendix D: For Religion and Substance Use

D.1 List of Works on Religion and Substance Use

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Curriculum Vitae

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