# Essays on Endogenous Decision Points

by

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Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Economics in the Graduate School of Duke University
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# Abstract

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# Abstract

This dissertation explores the implications of endognenizing the times decisions are faced for intertemporal decision-making in a variety of contexts. Chapter 1 considers a standard, expected-utility maximizer whose preferences are inferred using standard protocols that influence the decisions that the agent considers. The treatment shows how these induced "decision points," if unaccounted for, can produce illusions of well-known preference anomalies. Capturing the endowment effect, if receiving a good compels the agent to consider the decision to consume it, then the willingness-to-accept (WTA) in exchange for the received good exceeds the willingness-to-pay (WTP) prior to its receipt. If eliciting time-preferences — i.e. being asked to evaluate an intertemporal tradeoff involving different quantities of the good — likewise compels the agent to consider the consumption decision, present bias arises in the form of a measured quasi-hyperbolic discount function with present bias factor $\beta < 1$. While reconciling the preference anomalies with core principles of standard utility theory, the results also suggest that the endowment effect and present bias — generally treated as distinct phenomena — are actually manifestations of an identical decision-purview effect. In fact, $\beta = \text{WTP}/\text{WTA}$.

Chapter 2 introduces a framework for bad habits (namely, addiction) based on endogenous decision points — i.e. the times a recurring decision is faced.

Cravings are interruptive decision points that force an individual to consider consumption while inflicting a small opportunity cost. By extinguishing the craving, addictive consumption brings a brief vacation from unwanted decision points. The development of a habit is jointly characterized by a rising frequency and a rising per-decision level of consumption, matching behavioral patterns that standard habit-formation models do not address. Integrating external cues, modeled as random decision points, consumption routines become regimented as addiction develops. Occasional users are most responsive to cues, while addicts are comparatively immune. With peer consumption as a decision point, the group model predicts synchronized consumption, homogeneous self-sorting, and herd behavior — including imitation of a stray peer.

Chapter 3 complements the endogenous decision points theory of addiction of the previous chapter with a multidisciplinary survey of addiction research, organized and interpreted through the lens of the theory. In particular, I present evidence to support formalizations and results for the three decision point representations: internal cravings, external cues, and peer consumption. This chapter also discusses how the theory may help integrate key addiction concepts from other fields into economic formalism. For instance, I examine the physiological microfoundations of the interval function for cravings, and explain why it can be different for two products (e.g. cigarettes and chewing tobacco) that deliver the same product (nicotine). Further, I describe how transitions between abstinence and addiction can be motivated solely in terms of the endogenous "interval function." Finally, I propose that the formal notion of cravings as decision points may shed light on three prominent symptoms of addiction currently outside the domain of economics: trouble sleeping, reduced appetite, and difficulty concentrating during withdrawal.

# Contents

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# 1

# Inadvertent Decision-Cues: Are the Endowment Effect and Present Bias Variations of the Same Experimental Artifact?

## 1.1 Introduction

Given the decision an agent faces, how does the agent choose? This question serves as the starting point for economic theory, which has come to be defined by its standard answer: the agent chooses according to his or her *consistent* preference ordering. While preference consistency remains at the heart of the standard decision-making model, behavioral economic researchers — drawing heavily on evidence from experimental studies — have highlighted compelling challenges to this assumption and have proposed alternative models that relax it.

Perhaps the two most well-known and successful challenges to preference consistency are the endowment effect and present bias. The *endowment effect* refers to the notion that individuals tend to value a good more after acquiring it, as experimental studies commonly show that minimum selling prices to relinquish an acquired good exceed maximum buying prices prior to acquisition (e.g. Thaler, 1980; Kahneman et al., 1990); the endowment effect opens the door to problematic preference reversals, as acquiring an apple may cause an individual who prefers an orange ex-ante to now prefer the apple. *Present bias* refers to the notion that individuals tend to be less patient to delay a present return than a future return, ceteris paribus, as experimentally-elicited discount functions exhibit disproportionately steep discounting over immediate time-horizons (e.g. Ainslie, 1974; Thaler, 1981). Present bias likewise generates a form of preference reversal, as an individual who prefers two apples the day after tomorrow to a single apple tomorrow may prefer the single apple when tomorrow arrives and it becomes immediately available.

While they have been similarly instrumental in motivating departures from consistent preferences, the endowment effect and present bias are regularly treated as distinct phenomena. To start, the endowment effect is inferred in static exchange settings involving multiple goods, while present bias is inferred from evaluations of intertemporal tradeoffs involving different quantities of the same good at different times. Further, the endowment effect casts doubt on the conventional representation of static *consumption preferences* through a utility function that is independent of current assets (or any other reference point); present bias instead confronts the conventional representation of *time preferences* through a discount function that devalues future utility at a constant rate. Consequently, the two anomalies have motivated nonstandard models of decision-making in separate branches of behavioral economics. The endowment effect is typically regarded as a manifestation of loss aversion, and as such, is explained in the context of prospect theory and related reference-dependent preference models (Kahneman and Tversky, 1979; Tversky and Kahneman, 1991; and Kőszegi and Rabin, 2006); accordingly, the endowment effect is often cited as evidence for prospect theory as an alternative to *expected utility* theory, the standard model of choice under uncertainty (von Neumann and Morgenstern, 1944).[1] Present bias is typically equated to quasi-hyperbolic discounting (Laibson, 1997; O'Donoghue and Rabin, 1999); in turn, present bias is often regarded as the main challenge to *discounted utility* theory, the standard model of choice over time (Samuelson, 1937; Koopmans, 1960), of

[1]Although prospect theory is commonly cast as an alternative to expected utility as a model of risky choice, its defining feature — loss aversion — can be illustrated equally well in the realm of riskless choice. The endowment effect can be regarded as the quintessential illustration of loss aversion in its purest form, i.e. in an environment that generally abstracts from the inessential complication of risk.

which constant discounting is a central pillar.[2]

In operationalizing the notion that an agent chooses according to a consistent preference ordering, standard decision-making models employ a convenient simplifying assumption regarding the *decisions* the agent faces. Namely, it is standard practice to take decisions as given. In a dynamic setting, this implicitly assumes that the agent faces the same decision once in each "period," where the periods are exogenously and evenly spread across time.[3] While it is not generalizeable to the real-world experience of decision-making — we do in fact consider different decisions at different points in time — the usual treatment of decisions has gone unquestioned in the influential behavioral literatures that have cast doubt on preference consistency. When fitting these models to the experimental evidence, this maintained assumption presumes that protocols have no impact on the decisions the subject considers. For instance, in a typical experiment revealing the endowment effect, it is implicitly assumed that receiving a good has no influence on one's propensity to consider the decision to consume it; in a typical experiment revealing present bias, it is similarly assumed that being asked questions about a good (as in standard time-preference elicitation methods) has no bearing on one's propensity to consider the decision to consume it.

This paper presents a simple model to show how the endowment effect and present bias can emerge as experimental artifacts in a clean and straightfor-

[2]This paper follows the usual convention of defining quasi-hyperbolic discounting as time preferences that can be represented by the discount function $\beta\delta^t$, where $\beta, \delta \in (0, 1)$. Although it falls under the umbrella of quasi-hyperbolic discounting according to this paper's definition, Benhabib and Bisin (2008) and Benhabib et al. (2010) separately introduce a "fixed-cost" present bias to explain the experimental data. See section 1.5 for details.

[3]By no means is this assumption a fundamental tenet of classical utility theory, yet this convention pervades economic modeling, presumably in large part because it facilitates computation and empirical analysis.

ward way from a utility-maximizer's consistent preferences. To do so, the model departs from the usual simplifying assumption that the agent considers the same decision at every point in time. Instead, exposure to a *cue* associated with a given consumption good compels the agent to consider the decision to consume it. In particular, I assume that: (i) receiving a good, and (ii) eliciting time preferences with respect to the good (e.g. asking "do you prefer one unit of the good now or two units tomorrow?") are cues for the associated consumption decision. Because the good's value is higher conditional on considering the decision than unconditionally, its worth rises whenever a cue is present.[4] As a result, both preference anomalies emerge as artifacts: the endowment effect arises because receiving the good triggers the consumption decision; present bias arises because time-preference elicitation triggers the consumption decision.

The model not only captures the endowment effect and present bias with core principles of standard utility theory intact, it also reveals an intimate link between the two preference anomalies, as both arise from an equivalent "decision-purview" effect. That is, standard experimental protocols reliably and inadvertently produce cues that shift the agent's purview of decision-making towards the good through cues, while momentarily boosting its value without affecting its return to consumption.

The remainder of this paper proceeds as follows. Section 3.6 briefly discusses relevant cue research, which will help motivate and contextualize the key premises on which the model is based. Section 1.3 presents the basic

[4]This observation holds because if the agent does not consider the decision, a good perishes before it can be consumed if is nondurable, or if it is durable, its present value is subject to additional discounting over the delay to its eventual consumption, i.e. to the next time the agent considers the decision.

model in which a utility-maximizing agent may or may not consider a decision of interest in a given period. The two subsequent sections introduce the two inadvertent cues at the heart of this paper and characterize their corresponding experimental "scenarios": the endowment effect arises when receiving the good is a cue in Section 1.4; present-bias arises when time-preference elicitation is a cue in Section 1.5. Section 1.6 proposes experimental controls for these decision-purview effects (and provides evidence that these controls do in fact work). In doing so, the results of this section show that controlled inference with an auxiliary good eliminates the endowment effect and present bias. Section 1.7 elaborates on the link between the endowment effect and present bias — in the laboratory as well as in the field. This section also addresses why, despite being variations on the same theme, the endowment effect and present bias are not commonly observed in tandem: because detection of one generally precludes detection of the other. The final section briefly concludes.

## 1.2 Cues: Background and Evidence

Broadly defined as any item or context associated with a given behavior, exposure to a *cue* typically increases one's propensity to engage in the behavior. The mechanism through which cues influence consumption behaviors is commonly attributed to the fact that cues signal availability of the good (e.g. Carter and Tiffany, 2001; Cornier et al., 2007). In economics, the precise formal representation of a cue tends to vary from model to model. In Laibson's (2001) cue-based consumption theory, cues affect consumption preferences. In Bernheim and Rangel's (2004) theory of addiction, cues trigger mistaken consumption by driving a wedge between choices and preferences.[5] Following Landry (2013), this paper formalizes a cue as a "decision point" in that a cue compels the agent to consider the decision of interest at the time of the cue's incidence. Although cues may motivate consumption through other channels, there is abundant support for the decision point representation, as neuropsychology research reveals that decision-making faculties are activated and directed towards the associated good in the presence of a cue.

## 1.3 Model

### 1.3.1 Benchmark Setup

In each period, $t = 0, 1, \ldots$, a utility-maximizing agent who discounts future utility at a constant rate *might* consider the decision to consume a particular good. The *decision points* are defined as the points in time that the agent considers this decision of interest. For any $t$, suppose the unconditional probability of a decision point is $\pi \in (0, 1)$. We assume (implicitly) that the instantaneous return to consumption is strictly increasing and that the good is perfectly perishable.[6] It follows that if $t$ is a decision point, the agent optimally chooses to consume the full period-$t$ endowment of the good. Hence, instead of specifying the quantity of the good in a given endowment, we only need to specify the endowment's consumption value, which is understood to be the

[5]To motivate their relaxation of alignment between choices and preferences, Bernheim and Rangel suggest that the decision-maker acts as if cues systematically (and momentarily) distort information in a manner that exaggerates their true consumption preferences. Bernheim and Rangel also note that if cues instead activate a present bias, the resulting model would be nearly equivalent to their mistake-based representation.

[6]Perfect perishability is assumed for ease of exposition and to adhere to classical demand theory formulations. As shown in Appendix 1.8.1, all results are (qualitatively) robust to the consideration of a durable good.

instantaneous return to consuming the endowment. If $t$ is not a decision point, the agent presumably partakes in some outside opportunity (perhaps the agent considers a different decision). Since it is equivalent to the opportunity cost of a decision point, the return to the outside opportunity will be referred to as the *decision opportunity cost*. For simplicity, the decision opportunity cost is normalized to 1.

In our *benchmark*, which refers to the control setting in which the agent is not yet subjected to an "experiment," the endowment of the good is normalized to zero in each period. The corresponding benchmark expected lifetime utility is:

$$U_0 = \sum_{t=0}^{\infty} \delta^t (1 - \pi) = \frac{1 - \pi}{1 - \delta}.$$

where $\delta \in (0, 1)$ is a constant discount factor.

### 1.3.2 Alternate Scenarios: Endowments and Cues

Now suppose the agent is subjected to alternate, "experimental" scenarios. Relative to the benchmark, an alternate scenario may involve changes to the endowment stream, to the decision point probabilities, or both. Let $(e, \tau)$ denote a time-$\tau$ endowment with consumption value $e$. For a scenario that features an endowment of this form but does not include any other changes to the benchmark, the expected lifetime utility is given by:

$$U[(e, \tau)] = U_0 + \pi \delta^\tau e.$$

This expression implies that the endowment's value, $\pi \delta^\tau$, is its present discounted consumption value weighted by the probability of a decision point.

This follows because $(e, \tau)$ provides $e$ utils in period $\tau$ if and only if $\tau$ is a decision point (and has no impact beyond $\tau$).

A *cue* for consumption can refer to any item or context associated with the consumption good. As described earlier, exposure to a consumption cue generally increases the propensity to consume the good and that one plausible channel through which this effect operates is that the cue increases the propensity to consider the associated decision. Hence, in the current framework, a "cue" refers to a stimulus that increases any decision point probability relative to benchmark. For ease of exposition, the formal results of this paper will derived using the simplest form of a cue, in which a cue guarantees a decision point at the time of its incidence and leaves all other decision point probabilities unaffected — this representation isolates the immediate impact of a cue and treats it as an all-or-nothing proposition. Thus, absent any accompanying changes to the endowment stream, the expected lifetime utility associated with a single cue at $t$ is

$$U[t] = U_0 - (1 - \pi)\delta^t. \tag{1.1}$$

Hence the cue's expected disutility, $-(1 - \pi)\delta^t$, is the expected present value of the decision opportunity cost, i.e. the discounted decision opportunity cost weighted by the probability that the decision point would not have occurred in the benchmark.

For a scenario that involves a cue and an endowment, the expected lifetime utility is given by

$$U[t;(e,\tau)] \;=\; \begin{cases} U_0 - (1-\pi)\delta^t + \delta^\tau e & \text{if } \; t = \tau \\ U_0 - (1-\pi)\delta^t + \pi\delta^\tau e & \text{if } \; t \neq \tau \end{cases} \tag{1.2}$$

As shown here, for scenarios that involve both, cues and endowments will be separated by a semicolon in the argument of $U$. From equation (1.2), if the endowment and the cue coincide, then the weight $\pi$ on the endowment's present value vanishes, which follows because a decision point is guaranteed by the concurrent cue. If the endowment and the cue do not coincide, then the net value of both is simply the sum of the individual values.

In general, a scenario can involve a sequence of cues, $\{t_i\}$ with $i = 1, \ldots, I$, along with a sequence of endowments, $\{(e_j, \tau_j)\}$ with $j = 1, \ldots, J$ and each $\tau_j \in \mathbb{N}$. The corresponding generalized expected lifetime utility expression is

$$U[\{t_i\};\{(e_j,\tau_j)\}] \;=\; U_0 \;-\; (1-\pi)\sum_{i=1}^{I}\delta^{t_i} \;+\; \sum_{j:\tau_j\in\{t_i\}}\delta^{\tau_j}e_j \;+\; \pi\cdot\sum_{j':\tau_{j'}\notin\{t_i\}}\delta^{\tau_{j'}}e_{j'}$$

The interpretation of this generalized expression is essentially the same as in (1.2). Any cue $t$ inflicts the discounted expected decision opportunity cost $\delta^t(1-\pi)$; any endowment $(e,\tau)$ has present value $\delta^\tau e$ if it coincides with a cue and $\pi\delta^\tau e$ if it does not.

### 1.3.3 Simplifications Inherent in the Cue Representation

While the cue representation described above will suffice to illustrate the main points, it is limited as a realistic depiction of how cues can affect decision points. First, it abstracts from any persistence. In practice, cues may have a persistent effect on future decision points if the agent remembers past cues or if a cue is a catalyst for planning future decision points — e.g. setting a mental reminder, or using an external planning device (such as a calendar) to schedule future decision points. Thus, the representation abstracts from memories, plans, and other channels through which the present decision may depend on past cues. The representation also abstracts from any uncertainty regarding the induced decision point. Realistically, a cue may only raise the likelihood of a decision point without guaranteeing it — especially if the cue competes with other stimuli.

To entertain an enriched cue formulation that allows for persistence and uncertainty, let $\pi_t^*$ denote the cue-induced decision point probability at $t$, which presumably can take any value between the benchmark probability and unity: $\pi_t^* \in [\pi, 1]$. The sum $\sum_t \delta^t(\pi_t^* - \pi)$ would be a natural measure of the cue's *salience* since it quantifies the cue's "impact," given as the present expected value of the induced decision point sequence. This continuous measure of salience contrasts the simple cue representation, which implies that any two cues must be equally salient. Moreover, since one cue at $t$ guarantees $t$ will be a decision point in the simple representation, a second cue at $t$ has no additive effect — i.e. the two cues together are no more salient than the single cue. Thus, the enriched formulation is better suited for comparisons between "quiet" and "loud" cues and also to account for the notion that two concurrent cues ought to be more salient than a single cue. Though superfluous for the formal results, we will revisit these enrichments as they will be useful in addressing real-world intricacies that the simple cue does not readily motivate and also in relating the theory to relevant research that uncovers nuances for laboratory inference of preferences.

## 1.4 Receiving the Good as a Cue

Suppose *receiving the good* is a cue to consider the decision to consume it.[7] Then, for a scenario in which the agent receives $(e, \tau)$, $\tau$ will be a decision point with certainty.

To characterize the value of the good to the agent, define *willingness-to-pay* (WTP) to receive an endowment as the net value of receiving it and *willingness-to-accept* (WTA) to sell the endowment as the value of retaining the endowment upon its receipt. WTP and WTA will be denoted by $p^P$ and $p^A$, respectively. This notation reflects the understanding that both measures can be related to prices, as WTP is the maximum price the agent is willing to pay to receive the endowment and WTA is the minimum price the agent is willing to accept to sell it. Relative to the benchmark, WTP and WTA associated with the endowment $(e, \tau)$ are thus given by:

$$\begin{aligned} p^P(e,\tau) &= U[\tau;(e,\tau)] - U_0 \\ p^A(e,\tau) &= U[\tau;(e,\tau)] - U[\tau]. \end{aligned} \tag{1.3}$$

Here, WTP is the change in expected lifetime utility upon receiving $(e, \tau)$, and WTA is the ensuing (absolute) change upon immediately relinquishing $(e, \tau)$.[8] Since relinquishing a received endowment does not change the fact that it had been received, the benchmark expected lifetime utility does not enter WTA;

[7] This representation follows naturally from the definition of a cue, as receiving the good entails exposure to an item associated with consumption. It also trivially fits with a key mechanism through which cues motivate consumption, as receiving the good signals (quite reliably) its own availability.

[8] If the "default" is something other than the benchmark, i.e. if it involves a sequence of cues

rather, the scenario in which $(e, \tau)$ is relinquished still entails a cue at $\tau$. Due to the irreversibility of this cue, simply receiving the good makes the agent "invested" in the associated consumption decision. Quantifies this effect, the first result captures the commonly-observed WTA/WTP gap, the standard marker of an endowment effect whereby an agent values a good more after receiving it:

**Proposition 1** [Endowment Effect]
*Relative to benchmark,* $p^A(e,\tau) - p^P(e,\tau) = \delta^\tau(1-\pi) > 0$.

**Proof.** Follows trivially from equations (1.1), (1.2), and (1.3). ■

Since receiving the good is a cue, the apparent endowment effect in Proposition 1 arises because the good's value is higher conditional on considering the decision to consume it than unconditionally. Reflecting this notion, the WTA/WTP gap is the expected discounted opportunity cost, $\delta^\tau(1-\pi)$, from being "stuck" having to consider the decision to consume a good that was relinquished immediately after its receipt. This result can also be interpreted as a form of loss aversion. Here, a loss looms larger than a gain because the loss associated with relinquishing a good is its full consumption value, while the corresponding gain is only the good's *net* value, i.e. its full consumption value minus the expected decision opportunity cost from the receipt-induced cue. Also note that the endowment effect vanishes as $\pi \to 1$. This observation reflects the fact that having to contemplate a relinquished good does not entail

$\{t_i\}$ and a sequence of endowments $\{(e_j, \tau_j)\}$, the general forms for WTP and WTA are

$$\begin{aligned} p^P(e,\tau) &= U[\tau \cup \{t_i\}; (e,\tau) \cup \{(e_j,\tau_j)\}] - U[\{t_i\}; \{(e_j,\tau_j)\}] \\ p^A(e,\tau) &= U[\tau \cup \{t_i\}; (e,\tau) \cup \{(e_j,\tau_j)\}] - U[\tau \cup \{t_i\}; \{(e_j,\tau_j)\}]. \end{aligned}$$

an opportunity cost if the agent would have considered the decision regardless of the cue.

If receiving the good has no persistent effect on decision points beyond the time of receipt (as implied by our cue representation; see Section 1.3.3), Proposition 1 suggests there will be no apparent endowment effect for goods received before they are "ripe" (or available) for consumption. That is, if $(e, \tau)$ is received prior to $\tau$ and if the cue lacks persistence, there will be no disparity between WTA and WTP. This prediction fits with Brosnan et al.'s (2012) finding that chimpanzees exhibit an endowment effect for tools that are immediately useful, but not for tools that aren't immediately useful. This finding — and the fact that it doesn't generalize to humans — is consistent with the contention that "prospective memory," i.e. the capacity to remember to perform a planned behavior at the appropriate time, is a uniquely human trait (Tulving, 2005; Suddendorf and Corballis, 2007).[9]

## 1.5 Elicitation of Time Preferences as a Cue

Now suppose *elicitation of time preferences* is a cue.[10] Time-preference elicitation involves asking the agent to indicate a preference between an immediate endowment of the good and a future endowment, where without loss of gen-

[9]Although some authors debate that it is a uniquely human capacity, prospective memory in nonhumans is at best far rarer than prospective memory in humans. In either case, it would be expected that any endowment effect for tools that aren't immediately useful would be far less noticeable for chimpanzees than for humans. Further, the qualitative difference across species can be motivated without prospective memory because, unlike humans, chimpanzees generally do not use external planning devices — which are another means through which cue persistence can arise.

[10]As before, this representation follows naturally from the definition of a cue, as time-preference elicitation entails exposure to a context associated with the consumption good. Since an immediate endowment is included as an option in the current setting, the representation again fits with a key mechanism through which cues motivate behavior, as time-preference elicitation signals availability of the good.

erality it is presumed elicitation occurs at time-zero.

The *elicited discount function*, denoted by $D_\tau$, measures the total discount from elicitation to period $\tau$, the time of the prospective future endowment $(e, \tau)$ offered as an option in elicitation. To be precise, $D_\tau$ is defined as the unique value such that the agent is indifferent between the future endowment $(e, \tau)$ and the immediate endowment $(D_\tau e, 0)$.[11]

We cannot yet specify $D_\tau$ because, without knowing the details of elicitation, the decision point probability in $\tau$ is ambiguous when $(e, \tau)$ is chosen. Surely if the agent *receives* $(e, \tau)$ in period $\tau$, then $\tau$ must be a decision point since receiving the good is a cue. That said, it is conceivable that $\tau$ may not be a decision point even if the future prospect is chosen. For instance, elicitation may only involve tradeoffs among hypothetical rewards.[12] As another example, the future prospect may actually be acquired at the time of elicitation (e.g. if the agent chooses among one yellow banana that is ripe today versus two green bananas that will be ripe tomorrow). To account for this possibility, the term *nonreceived* is used to refer to a good that does not come hand-in-hand with a cue. For some interpretations of a nonreceived good, the adjective "nonreceived" is an awkward fit. Nonetheless, the term is used to make clear that a nonreceived good represents the opposite of a received good with regards to the latter's formal cue representation.

**Proposition 2** [Present-Biased Discounting]

[11]Put differently, if elicitation reveals that the agent is indifferent between $(e', 0)$ and $(e, \tau)$, then $D_\tau = \frac{e}{e'}$. Note that $D_\tau$ may implicitly depend on $e$ (as well as $\pi$).

[12]For time-preference elicitation involving hypothetical rewards, it is often unclear whether subjects ought to choose the alternative that they would prefer to hypothetically own (i.e. to have in their initial endowment), in which case the future reward may not hypothetically involve a cue, or if subjects ought to choose the alternative that they would prefer to receive. For instance, consider an excerpt from the sample instructions in Thaler's (1981) classic study: "Choose between: (A.1) One apple today. (A.2) Two apples tomorrow."

*$D_\tau = \beta\delta^\tau$, where the measured present-bias factor $\beta < 1$ is given by:*

(i) $\beta = \left(1 - \frac{1-\pi}{e}\right)$ *for received goods,*

(ii) $\beta = \pi$ *for nonreceived goods.*

**Proof**. Given time-zero elicitation, for received goods, the expected lifetime utilities associated with $(e, \tau)$ and $(D_\tau e, 0)$ are, respectively,

$$U[0, \tau; (e, \tau)] = U_0 - (1 - \pi) - (1 - \pi)\delta^\tau + e\delta^\tau$$
$$U[0; (D_\tau e, 0)] = U_0 - (1 - \pi) + D_\tau e.$$

The indifference condition is $D_\tau e = \delta^\tau(e - (1 - \pi))$, which establishes part (i).

For nonreceived goods, the associated expected lifetime utilities are:

$$U[0; (e, \tau)] = U_0 - (1 - \pi) + \pi e\delta^\tau$$
$$U[0; (D_\tau e, 0)] = U_0 - (1 - \pi) + D_\tau e.$$

Now the indifference condition is $D_\tau e = \pi\delta^\tau e$, which establishes part (ii). ■

Proposition 2 shows how time preference elicitation produces an apparent present bias in that the elicited discount function is precisely the quasi-hyperbolic discount function. The measured present bias factor $\beta < 1$ will, in general, depend on whether or not choosing the future prospect coincides with a cue (i.e. depending on the "type" of good). For part (i) the present bias for received goods assumes the form a a "fixed-cost" present bias in which the agent appears to discount as if future returns entail a fixed cost from which present returns are exempt.[13] The magnitude of this fixed cost is the expected decision opportunity cost, $1 - \pi$. Thus, in this vein, the measurement of a fixed-cost present bias arises because the fixed cost is "sunk" for the

[13]See Benhabib and Bisin (2008) and Benhabib et al. (2010).

immediately-received good — the valuation of the immediately-received good. That is, the value of the immediate prospect is momentarily inflated relative to future prospects because the decision opportunity cost of a receipt-induced cue has already been paid due to the cue from elicitation.

From part (ii) of Proposition 2, for nonreceived goods the measured present bias factor is simply $\pi$, the benchmark decision point probability. In this case, the appearance of present bias arises because because an accompanying decision point is not assured for the future prospect. Only the immediate endowment's full consumption value can be realized with certainty due to the elicitation-induced decision point; if the agent selects the future endowment, however, the agent may "forget" to consider the decision, and hence runs the risk that the good will perish without being consumed.[14]

Time-inconsistent preferences can be inferred from either form of measured present bias because both can generate apparent preference reversals in the usual way. For instance, if $e' \in (\beta\delta e, \delta e)$, then $(e, 2)$ is preferred to $(e', 1)$ since $\delta e > e'$; yet a reversal becomes evident if each prospect is shifted forward one period, in which case $(e', 0)$ would be preferred to $(e, 1)$ since $e' > \beta\delta e$.

As with the endowment effect, the measured present bias (in both forms) vanishes as $\pi \to 1$. For received goods, this observation reflects the fact that an expected future receipt-induced decision opportunity cost is zero if the future decision point was assured regardless of the cue. For nonreceived goods, present bias disappears as $\pi \to 1$ because the agent is not disproportionately "invested" in the good at the time of elicitation if decision points are guaran-

[14]While the inference of present bias here is robust to consideration of durable goods (as shown in Appendix 1.8.1), the interpretation is different. With durable goods, the present bias factor reflects the "extra" discounting from the time that the future good is first available until the eventual time of consumption (i.e. the first cue on or after the time the good is first available for consumption).

teed in future periods too.

Note that for received goods, an endowment's consumption value nontrivially enters as an argument in the elicited discount function. This dependence gives:

**Corollary 1** [Magnitude Effect] *For received goods,* $\dfrac{\partial D_\tau}{\partial e} > 0$.

**Proof**. For received goods, $\frac{\partial D_\tau}{\partial e} = \delta^\tau \frac{1-\pi}{e^2} > 0$. ∎

Corollary 1 asserts that the elicited discount function for received goods is increasing in the consumption value of the prospective future endowment. This result captures the widely-documented *magnitude effect* — an inherent feature of the fixed-cost present-bias — whereby individuals appear to be more patient for large rewards than for small rewards, ceteris paribus.[15] Hence, the magnitude effect arises because the expected opportunity cost of a future receipt-induced decision point is comparatively small when the consumption value of the received good is large. Put differently, if the agent waits to receive $(e, \tau)$, the "annoyance" from having to consider the decision (again) at $\tau$ is relatively minor if the future reward $e$ is large.

## 1.6 Controlling for Decision-Point Effects

Arguably, the primary advantage of laboratory experiments is the control they offer over the many factors that can influence decision-making.[16] The results derived in the current framework, however, suggest that standard laboratory

[15] In addition to Benhabib et al.'s (2010) findings, the magnitude effect is evident from survey data in Thaler (1981), Benzion et al. (1989), and Green et al. (1997). See Loewenstein and Prelec (1992) or Frederick et al. (2002) for discussion and additional references. For a recent axiomatization of the magnitude effect, see Noor (2011).

[16] See Smith (1982), page 930; and Davis and Holt (1993), page 15.

protocols are not suitably controlled to test fundamental preference consistency assumptions. Namely, standard protocols are confounded by inadvertently induced decision points that can lead an agent with consistent preferences to falsely exhibit the endowment effect and present bias. In both cases, the agent is disproportionately invested in the good that is available or in hand now because laboratory cues compel the agent to consider the associated consumption decision. In a sense, peer effects inherent in the agent's interactions with the experimenter compromise the control that motivated the experiment.

Is there a way to control for decision-point effects? As discussed, if decision points are guaranteed in every period, the temporal structure reduces to monolithic discerete-time, which debiases measurement so that consistent preferences are inferred. However, guaranteeing decision points for all time is not a practical experimental control. That said, for our simple cue that guarantees a decision point upon arrival and leaves all other decision point probabilities unaffected, feasible controls exist since decision points would then only need to be guaranteed in periods relevant to the valuation problem.

For a simple cue, a sufficient control would be to modify the benchmark to include the receipt of an *auxiliary endowment* of the good, denoted by $(a, \tau)$ with $a > 0$, where $\tau$ is the same period associated with the primary endowment $(e, \tau)$ that the agent evaluates. This modified benchmark will be referred to as the *auxiliary-appended benchmark*.

**Proposition 3** [Reference Independence]
*Relative to the auxiliary-appended benchmark,* $p^A(e, \tau) = p^P(e, \tau)$.

**Proof**. Given the receipt of $(a, \tau)$, WTP for $(e, \tau)$ is the value with both endowments minus the value with $(a, \tau)$ only, while WTA for $(e, \tau)$ is the value with both endowments minus the value with $(a, \tau)$ only, conditional on receipt of $(e, \tau)$:[17]

$$p^P(e, \tau) = U[\tau, \tau; (a, \tau), (e, \tau)] - U[\tau; (a, \tau)] = U[\tau; (a+e, \tau)] - U[\tau; (a, \tau)] = \delta^\tau e,$$

$$p^A(e, \tau) = U[\tau, \tau; (a, \tau), (e, \tau)] - U[\tau, \tau; (a, \tau)] = U[\tau; (a+e, \tau)] - U[\tau; (a, \tau)] = \delta^\tau e.$$

Thus $p^A(e, \tau) = p^P(e, \tau)$. ■

This result shows how the auxiliary endowment can negate the receipt-induced decision point responsible for the WTA/WTP gap, thereby eliminating the endowment effect in Proposition 1. Colloquially, Proposition 3 implies that the endowment effect is eliminated if the agent has already received the same good. This prediction is consistent with Morewedge et al.'s (2009) finding that potential buyers of a coffee mug who already happen to own an identical mug are generally willing to pay the price demanded by sellers.[18]

Proposition 3 ought to remain valid even if the auxiliary endowment is a different good that, when received, triggers the same decision as the primary good. Since different goods may be consumed in a similar fashion, it is plausible that such "decision-point substitutes" exist. This concept fits with Chapman's (1998) finding that the endowment effect is significantly more pro-

[17] Note that since both endowments correspond to the same period, the valuation associated with having both endowments only needs one cue ($\tau$) in its argument. As with WTP, a second cue in the valuation associated with having both endowments will be redundant in expressing WTA. Now, however, the redundancy also exists in the expression associated with relinquishing the received endowment $(e, \tau)$. Hence, since receiving $(a, \tau)$ assures a decision point at $\tau$, conditioning on having received $(e, \tau)$ is irrelevant to the valuation.

[18] While the authors likewise interpret their results as diminishing the necessity (or importance) or loss aversion, Morewedge et al. attribute the endowment effect to ownership. That is, Morewedge et al. suggest that merely owning a good may strengthen revealed preferences for the good, in part because individuals have an incentive to justify their choices and in part because individuals associate the goods they own with themselves.

nounced between a chocolate and a writing utensil than between two different types of chocolates (or between two different types of writing utensils), i.e. individuals endowed with a chocolate are generally far less reluctant to exchange it for a different type of chocolate than to exchange it for a writing utensil of similar value (and vice versa).[19] In the present setup, an auxiliary endowment can presumably negate the receipt-induced decision point for a different type of that good if both induce an equivalent decision point. However, the endowment effect remains if the auxiliary endowment triggers a different decision altogether — i.e. receiving a writing utensil cannot serve as a proper control for chocolate because a writing utensil would not compel the agent to consider the decision to eat (and vice versa, because a chocolate would not compel the agent to consider writing).

The same principle that eliminated the WTA/WTP gap can applied to eliminate the elicited present bias. That is, if time preferences are elicited as before, except now the auxiliary endowment is received at the time of the primary prospective future endowment (regardless of the agent's stated preference), the elicited present bias vanishes:[20]

**Proposition 4** [Constant Discounting]

*From the auxiliary-appended benchmark,* $D_\tau = \delta^\tau$.

**Proof**. Given time-zero elicitation of time-preferences, the value of receiving

[19]Similar evidence is provided by Hanemann (1991) and by Shogren et al. (1994) who find that goods with more substitutes in the marketplace feature a smaller WTA/WTP gap than goods with fewer substitutes.

[20]Stated differently, if the original procedure compared $(e', 0)$ to $(e, \tau)$, now the pairs $\{(e' + a, 0), (a, \tau)\}$ and $\{(a, 0), (e+a, \tau)\}$ are compared. In the constructed experimental setting, receiving $(a, 0)$ for both options is extraneous, but realistically it may be a helpful control to ensure the present cue is as potent as the future cue even when the agent opts for the alternative with the larger consumption value at $\tau$.

$e+a$ at $\tau$ and $a$ now versus receiving $a$ at $\tau$ and $D_\tau e+a$ now are, respectively,

$$U[0,\tau;(a,0),(e+a,\tau)] = U_0 - (1-\pi) - (1-\pi)\delta^\tau + a + (e+a)\delta^\tau$$
$$U[0,\tau;(D_\tau e+a,0),(a,\tau)] = U_0 - (1-\pi) - (1-\pi)\delta^\tau + D_\tau e + a + a\delta^\tau.$$

The indifference condition is $D_\tau e = \delta^\tau e$, which gives the desired result. ■

Receiving the auxiliary endowment restores constant discounting because, with a guaranteed cue at $\tau$ along with the elicitation-induced cue at time-zero, a decision point is a foregone conclusion at both times, thus equalizing the agent's "investment" in the current decision point. Proposition 4 pertains to time-preference elicitation for received and nonreceived goods, although it is easier to conceive implementation for received goods for consistency with how $(a,\tau)$ is acquired. For received goods, there is no longer a fixed cost associated with $(e,\tau)$ because — as with the time-zero cue — the expected decision opportunity cost is already sunk for $\tau$, which wipes out the apparent fixed-cost present bias from part (i) of Proposition 2. For nonreceived goods, the agent is no longer uncertain if a decision point would accompany $(e,\tau)$ because it is guaranteed by the auxiliary endowment; thus the value of $(e,\tau)$ is no longer weighted by the benchmark decision point probability, $\pi$, which was also the measured present bias factor from Proposition 2, part (ii).

Although it would have been unnecessary to do so, Proposition 4 would continue to hold if the agent received an additional auxiliary endowment at time-zero. If so, both alternatives in the elicitation task would involve a pair of endowments — one at time-zero and one at $\tau$ — that differ only in their consumption values at each time. Thus, Proposition 4 implies that the elicited present bias vanishes when characterizing preferences over a sequence of outcomes at prespecified times. This implication fits with evidence of exceedingly low discounting inferred from preferences over sequences of outcomes (Loewenstein and Prelec, 1991 and 1993).[21]

## 1.7 Linking the Endowment Effect and Present Bias

### 1.7.1 Relationship in the Laboratory

The results from Sections 1.4-1.5 illustrate how, in a typical laboratory setting, the endowment effect and present bias can both emerge as artifacts from experimentally-induced decision points. Section 1.6 then shows how both preference anomalies can be erased using the same experimental control — an auxiliary endowment of the same good. The endowment effect and present bias arise due to a common incentive to own a consumption good "now" (at the time of the cue), reflecting the same underlying principle: since considering the consumption decision is a necessary precursor to consumption itself, the good is more valuable conditional on considering the decision to consume it than unconditionally.

Basic comparative statics reinforce the connection between the endowment effect and present bias. First, increasing $\pi$ helps bring both the WTA/WTP gap and the measured present bias factor closer to their classical values (0 and 1, respectively). This relationship means both anomalies ought to be more pronounced for goods that the agent considers consuming infrequently than for frequently-considered goods. Although the decision opportunity cost was

[21] In fact, both cited studies demonstrate revealed *negative* time preferences (i.e. an effective discount function that increases with $t$), as individuals prefer an improving sequence of outcomes over a constant sequence holding total consumption value fixed.

normalized to 1, it is straightforward to posit changes to the this value and to see, for received goods, that increasing the decision opportunity cost would drive both the WTA/WTP gap and the measured present bias factor away from their classical values. This comparative static suggests that the agent's true, classical preferences would be inferred if only the agent had nothing better to do, i.e. if the agent is undeterred by the fact that outside opportunities cannot be entertained at the time of a receipt-induced cue. Conversely, if the decision opportunity cost rises, both preference anomalies become more conspicuous since the incentive to avoid an extra receipt-induced cue also rises.

Even still, the quantitative link between the endowment effect and present bias can be tightened. For a good that induces a lone decision point upon its receipt, the measured present bias factor is in fact equal to the ratio between WTP and WTA:

**Proposition 5** [Equivalence]

*For a future endowment, WTP is its measured discounted consumption value (i.e. discounted according to the elicited discount function) and WTA is its true discounted consumption value, so that the WTP/WTA ratio equals the measured present bias factor:*

$$p^P(e,\tau) = \beta\delta^\tau \ \ \textit{and} \ \ p^A(e,\tau) = \delta^\tau, \ \ \textit{which gives} \ \ \beta = \frac{p^P(e,\tau)}{p^A(e,\tau)} < 1.$$

**Proof.** Follows trivially from equations (1.1), (1.2), and (1.3), along with the definition of $\beta$ (for received goods) as given in Proposition 2, part (i). ■

Both WTP and the measured discounted consumption value (i.e. with the present bias) represent the value of receiving the good net the expected decision opportunity cost. WTA matches the true discounted consumption value because both reflect the value of retaining the good when the decision opportunity cost is already sunk. Again, this disparity reflects the irreversibility of the receipt-induced cue: while the cue arrives in a package deal with the received good, the cue cannot be "repackaged" with the good when the good is re-sold.

Since receiving a good and time-preference elicitation induce decision points in an identical manner, either cue should suffice to generate either preference anomaly. That is, an experiment that uncovers either the endowment effect or present bias in fact produces both anomalies — one of which is generally observed, while the other is unobserved. For instance, receiving a good — as in a typical laboratory experiment that illustrates the endowment effect — decreases the necessary consumption value of an immediate endowment such that the agent is indifferent between the immediate endowment and a given future endowment, ceteris paribus, thereby generating an unmeasured present bias that will go unnoticed because such experiments do not elicit discount functions. Conversely, time-preference elicitation can raise the immediate good's value to the agent relative to the benchmark WTP, but this version of an endowment effect induced by time-preference elicitation similarly remains hidden.

### 1.7.2 Relationship in the Field

Since WTA and WTP map to prices, it is possible to observe the endowment effect in conventional markets for the good. Accordingly, field studies have demonstrated the endowment effect in a a variety of markets, such as an insurance market (Johnson et al., 1993), a sportscard market (List, 2003), and a stock market (Furche and Johnstone, 2006).[22] Evidence of present bias in the field, however, is not typically found in the markets for the primary goods for which present bias is thought to induce preference reversals. Instead, to detect present bias in the field, researchers look at markets for a special type of substitute to the good: a *commitment device* that restricts availability of the primary consumption good.[23] Accordingly, define the *commitment value*, denoted by $p^C(e, \tau)$, as the maximum price that the agent is willing to pay for a commitment device that restricts the availability of $(e, \tau)$ by preventing its receipt.[24]

If the endowment effect is inferred from a WTA/WTP gap and if the agent had to voluntarily buy the good for a WTA/WTP gap to be observed, then the endowment effect can only be inferred if WTP is positive. If present bias is inferred from demand for commitment, then present bias can only be inferred if commitment value is positive. Given these restrictions, the next result shows that the two anomalies cannot be simultaneously detected for the same good.

**Proposition 6** [Mutual Exclusivity in the Field]

[22] List's study features an interesting disclaimer as it demonstrates a strong endowment effect for inexperienced traders only. The trading behavior of sufficiently experienced traders is actually more or less consistent with neoclassical demand theory. The induced decision point concept embeds a natural explanation for this observation: since experienced traders are accustomed to trading the sportscards they receive, it is quite plausible that a sportscard becomes a cue to consider the decision to trade it — as opposed to the decision to "consume" it. Consequently, the cue does not raise the valuation of having the card because it becomes associated with a different activity (trading) that does not involve keeping it. Also see Coursey et al. (1987) for similar evidence that the WTA/WTP gap diminishes with market experience.

[23] As O'Donoghue and Rabin (1999) describe, "Researchers looking for empirical proof of time-inconsistent preferences often explore the use of self-limiting 'commitment devices' (e.g., Christmas clubs, fat farms), because such devices represent 'smoking guns' that cannot be explained by any time-consistent preferences." For a review of commitment devices, see Bryan et al. (2010).

[24] The notion that a commitment device restricts availability by preventing the cue fits with the common contention that cues motivate consumption by signaling availability of the good.

*If* $e > 1-\pi$, $p^P(e,\tau) > 0 > p^C(e,\tau)$; *if* $e < 1-\pi$, $p^C(e,\tau) > 0 > p^P(e,\tau)$.

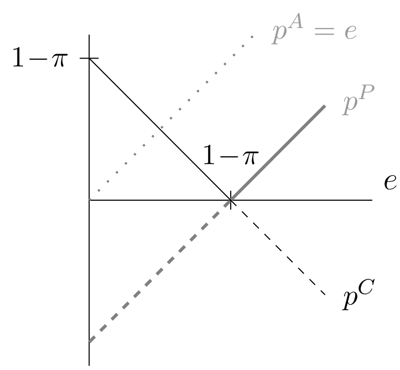
**Proof**. $p^P(e,\tau) = U[\tau;(e,\tau)] - U_0 = \delta^\tau[e - (1-\pi)]$. $p^C(e,\tau) = U_0 - U[\tau;(e,\tau)] = \delta^\tau[(1-\pi) - e] = -p^P(e,\tau)$. Therefore, the sign of $e-(1-\pi)$ must agree with the sign of $p^P(e,\tau)$ and disagree with the sign of $p^C(e,\tau)$. ■

Proposition 6 shows that WTP and commitment must have the opposite sign (unless both equal zero). Although this result follows trivially from our definitions — commitment value is the negative of WTP — it has significant ramifications for the relationship between the endowment effect and present bias. Namely, it implies that, in the field, feasible detection of the endowment effect precludes feasible detection of present bias (and vice versa). The endowment effect is only observable (positive WTP) for goods in which the consumption value exceeds the expected opportunity cost of a decision point; present bias is only observable (positive commitment value) for goods in which the consumption value is less than the expected decision opportunity cost.

Hence, as in turns out, the relationship between the endowment effect and present bias in the field parallels their relationship in the laboratory in that the two anomalies will not be simultaneously detected using conventional means of inference. That said, mutual exclusivity in the field holds for a different reason: because the endowment effect is apparent only for sufficiently high-value goods while present bias is apparent only for sufficiently low-value goods. Whereas, in the laboratory, both anomalies are observable for a given good, but only one is observed in practice because standard protocols only measure one anomaly.

Just as the endowment effect is observable in the domain of goods for which commitment has no relevance, present bias is observable in the domain of goods for which loss aversion has no relevance. Namely, the overall effect of receiving and then subsequently relinquishing a good for which commitment has value is costly, but it cannot be cast as a gain and subsequent loss of greater magnitude because receiving the good was not a loss itself. That is, the endowment doesn't break even in that its consumption value is less than the expected discounted opportunity cost associated with its receipt. Moreover, if $e < \frac{1-\pi}{2}$, the magnitude of the initial net loss from receipt — i.e. the change in the value that is typically classified as the "gain" — exceeds that of the ensuing loss.

The domain-specificity is illustrated below:




Above the threshold consumption value, $e > 1 - \pi$, the endowment effect can be inferred from a disparity between WTA and WTP. Below the threshold consumption value, $e < 1 - \pi$, present bias can be inferred from demand for commitment. Note that if either the good or the commitment device (or both) has a monetary price, then there would be a nontrivial range of consumption values that would include $e = 1-\pi$ for which neither the good nor the commitment device will be purchased; in this case, neither the endowment effect nor present bias will be detected.

## 1.8 Appendix

### 1.8.1 Proof that Results Generalize to Durable Goods

Now assume the good is durable. Then the benchmark expected lifetime utility and the expected lifetime utility with a cue at $t$ are unchanged:

$$U_0 = \sum_{t=0}^{\infty} \delta^t (1-\pi) = \frac{1-\pi}{1-\delta}.$$

$$U[t] = U_0 - (1-\pi)\delta^t.$$

The expected lifetime utility for the endowment $(e, \tau)$ is now

$$U[(e,\tau)] = U_0 + \sum_{k=0}^{\infty} \pi \delta^{\tau+k} (1-\pi)^k e = U_0 + \frac{e\pi\delta^\tau}{1-\delta(1-\pi)}.$$

For a scenario that involves a cue at $t$ and an endowment $(e, \tau)$, the expected lifetime utility is thus

$$U[t;(e,\tau)] \; = \; \begin{cases} U_0 - (1-\pi)\delta^t + e\delta^\tau & \text{if } \; t = \tau \\ U_0 - (1-\pi)\delta^t + \dfrac{e\pi\delta^\tau}{1-\delta(1-\pi)} & \text{if } \; t \neq \tau \end{cases} \tag{1.4}$$

It is readily verifiable that Proposition 1, part (i) of Proposition 2, Corollary 1, and Propositions 6–4 do not need to be changed to accommodate durable goods because they hold exactly as they did for perishable goods. For part (ii) of Proposition 2, the result holds except we need to modify the measured present bias factor for nonreceived goods, as it is now given by

$$\beta = \frac{\pi}{1-\delta(1-\pi)} < 1.$$

This expression can be derived from the indifference condition $U[0;(e,\tau)] = U[0;(D_t e, 0)]$ using Equation (1.4).

# 2

# Bad Habits and Endogenous Decision Points

## 2.1 Introduction

The choices we select crucially depend on the *decisions* we consider — I cannot choose to buy a product without *considering the decision* to buy it. Where do decisions come from? Why do certain decisions arise when they do? Can our choices influence the timing of future decisions? These questions have remained outside the scope of economic analysis because standard practice takes the times decisions are faced as given. In models with repeated choices, it is customary to assume time is "metronomic." An inherent feature of the standard continuous and discrete-time ($t = 0, 1, 2, \ldots$) specifications, *metronomism* entails an exogenously-fixed "decision schedule" in which decisions are evenly spread across time — akin to a practicing musician who uses a clicking metronome to establish a fixed rhythm.

While often an empirical necessity, the rigidity of standard time is a major theoretical limitation in the realm of *habits*.[1] Given that the development of a habit is generally characterized by a growing *frequency* of the behavior, metronomism is not amenable to accurate micro-level descriptions because, in a standard interior solution, the fixed time-interval between decisions implies a fixed consumption frequency. In particular, I argue a new representation of time is needed to capture the incentives and consumption patterns that define *addiction* — a potentially troublesome habit for utility theory since addictions seem to bring more harm than benefit.

This paper develops a new framework for bad habits based on "endogenous

[1]According to conjectures by researchers in psychology, habits constitute a substantial portion of our everyday activities. From diary accounts of day-to-day behavior, Verplanken and Wood (2006) estimate 45% of documented actions were habits. Other studies contend *most* behavior is habitual (Louis and Sutton, 1991; Verplanken et al., 2005).

decision points." The *decision points* are the points in time ($t = t_0, t_1, \ldots$) an individual faces a decision of interest. The basic model is predicated on the role of *cravings*, which are modeled as decision points, i.e. a craving forces the individual to consider consumption. The decision point is a natural formalization because when cravings strike, an addict becomes fixated on the object of dependence: as neuropsychology findings indicate, cravings reorient decision-making faculties towards the craved good.[2] Due to their interruptive nature, each craving involves a *decision opportunity cost*, the loss from needing to momentarily pause outside opportunities. With the decision opportunity cost as the only payoff parameter in the basic model, the individual never wants to face the decision.

Two core assumptions relate choices to the timing of future decisions: (i) by strengthening the habit, consumption increases the frequency of cravings in the long-run; and (ii) consumption *reduces* the frequency of cravings in the short-run, by increasing the time-interval to the next decision. As it involves frequent unwanted decisions, a strong habit can be "bad" simply because having to face the decision wastes valuable time. However, the short-run effect embeds a strategic motive to consume as a means to delay imminent cravings, allowing normal life to continue uninterrupted in the interim. This, I argue, is a key incentive underlying addictive behavior.

Proposition 7 establishes conditions for a stable, addicted steady-state with a "slippery slope" equilibrium path (from an unstable, zero-consumption steady-

[2]The phrase "reorients decision-making faculties" refers to what psychologists may describe as enlistment of "cognitive control resources" or as prompting an "attentional switch." It can be seen from neuroimaging data that drug cravings activate working memory systems (Grant et al., 1996; Garavan et al., 2000); as Garavan and Stout (2005) describe, "working memories are occupied with drug craving thoughts and ruminations."

state). Behavior under addiction is jointly defined by the frequency and the level of consumption, which fits with pharmacological evidence: as Benowitz (1991) describes, addiction involves "certain rates of delivery and certain intervals between doses." Both the frequency and the level are higher in the addicted steady-state than for weaker habits along the path to addiction. Introducing *negative* direct returns to consumption, an intermediate, unstable steady-state emerges that corresponds to occasional consumption (Proposition 8). The emergent steady-state accounts for the concurrent rises in the costs of smoking and in the prevalence of occasional smokers; its instability qualitatively matches the finding that low-frequency smoking is a highly unstable status relative to being addicted.

Demand under addiction admits "interval-driven adjacent substitution." Established by Corollary 2, *adjacent substitution* means demand in the near-term future falls with present consumption — i.e. the good now and in the immediate future are substitutes. Consistent with laboratory evidence on smoking behavior, adjacent substitution is *interval-driven* because the time-interval to the next instance of consumption increases with current use.[3] The interval-driven aspect is key to the puzzle of harmful addiction, as it embeds the underlying incentive. Further, interval-driven adjacent substitution reflects the value of *consumption* as a short-term commitment device, in that it delays the next opportunity to consume. Another noteworthy characteristic of addictive demand is *distant complementarity*, i.e. the good now and in a sufficiently distant future are complements, which holds in large part because

[3]Dallery et al. (2003) find the latency to smoke is substantially longer following rapid smoking relative to normal paced smoking. Zacny and Stitzer (1985) similarly demonstrate the latency to smoke decreases after nicotine deprivation.

the long-run frequency of decisions rises with present consumption.

Even if choices generated from endogenous decision points are aggregated to discrete-time, *measured* adjacent substitution (substitution between consecutive measurement periods) suffices to distinguish the model from prevailing standard-time habit and addiction models, provided the data aren't too coarse (Proposition 10). Most notably, measured adjacent substitution contrasts Becker and Murphy's (1988) "rational addiction" theory, which defines addiction as adjacent complementarity. Inferring preferences with discrete-time aggregation produces "omitted decision-point biases," as recorded by Proposition 11. The estimates reconcile anomalous discounting patterns — severe impatience, commodity-dependence, and endogenous time preference — prominent in research on addiction. The procedure also captures the predominant, time-inseparable "habit-formation preferences" as an artifact of misspecification. These inferred preference structures encompass the default tools to explain bad habits in metronomic time; for instance, rational addiction theory uses habit-formation preferences and severe impatience to motivate harmful consumption habits. The portrayal of habit-formation preferences as an omitted variable bias is consistent with the neuropsychology conclusion that drugs are 'wanted' more-and-more despite not being 'liked' more-and-more in the course of addiction.

In Section 5, *external cues* are modeled as stochastic decision points and integrated into the basic framework. The representation of cues as decision points follows from cravings as decision points because external cues induce internal cravings. Consistent with evidence, the model predicts occasional users are the most sensitive to stochastic cues, while addicts' consumption patterns are less random and largely independent of external cues (Proposition 12). These effects arise because the relative force of external cues dwindles in lieu of internal dependence.

As the behavior of others often constitutes a cue, *peer consumption* is modeled as a decision point in Section 2.5. Propositions 14-16 capture three aspects of group conformity that give rise to positive peer effects: synchronized consumption, self-sorting into homogeneous groups, and herd-behavior within homogeneous groups. Synchronization improves group welfare because a peer's consumption is a negative "decision externality" unless the individual is already facing the decision. When group formation is endogenous, less frequent users avoid more frequent users as a commitment strategy to avoid facing frequent decisions, which drives homogeneous self-sorting. Within a homogeneous group, imitation is optimal even if a deviant strays from the equilibrium path, as a herd will follow to keep everyone's decision point schedules aligned. In the vicinity of an unstable steady-state, such herd effects can trigger collective group transitions (i.e. starting and quitting) in both directions.

*Negative* peer effects, however, arise from "coerced heterogeneity," in which an addict effectively imposes discrete-time decision-making on the less habituated (Proposition 17). The low-habit peers eventually quit because the addict's presence eliminates the incentive to consume beyond the amount necessary to endure without a craving until the addict's next decision point. A strategy for implementing coerced heterogeneity in the laboratory is discussed, which lends itself to a simple method to identify "natural" decision points — namely instructing the subject to preprogram the times the good is made available (where each offer is a decision-inducing cue).

Motivating evidence is mostly relegated to this paper's complement, Landry (2012). The complementary paper, abbreviated as BH-C (Bad Habits – complement) from here forward, provides a multidisciplinary survey of addiction research, organized around and understood through the lens of the decision points model. The bulk of cited evidence in both papers pertains to tobacco use because smoking serves as an intuitive illustration of the model and also because cigarette addiction is unrivaled in scale among harmful addictions.[4]

## 2.2 Basic Model: Cravings as Decision Points

An individual faces a repeated decision indexed by $i = 0, 1, 2, \ldots$. The *decision points*, $(t_0, t_1, \ldots)$, are the chronologically-ordered times the decision is faced. When not considering the decision of interest, there is a presumed desirable outside opportunity. Decision points interrupt the outside opportunity; due to these interruptions, each decision point entails a *decision opportunity cost*. For simplicity, the decision opportunity cost is normalized to $-1$, so its time-profile looks like this (where each dot represents a single payment of the decision opportunity cost):


At each decision point, the individual chooses consumption $c \in [0, 1]$ and receives instantaneous utility $u(c)$. If a decision point $t_i$ is a known, deter-

[4]There are one billion smokers who smoke nearly six trillion cigarettes a year, sustaining an industry that collects nearly a half-trillion dollars in annual revenues from a product projected to kill one billion people during the 21st century (Eriksen et al., 2012).

ministic function of the choice history, $((c_{i-1}, t_{i-1}), (c_{i-2}, t_{i-2}), \ldots)$, where each choice is defined by the level and the time of consumption, then the individual chooses the consumption sequence $(c_0, c_1, \ldots)$ to maximize lifetime utility

$$U = \sum_{i=0}^{\infty} \delta^{t_i}(-1 + u(c_i)). \tag{2.5}$$

Lifetime utility is summed over the decision index $i$ and expressed relative to the outside opportunity — i.e. if the individual never faces the decision, lifetime utility would be zero.

To allow recursive computation of decision points, the *interval function*, denoted by $\tau$, is defined as the time-duration from the current decision to the next:

$$\tau(s_i, c_i) = t_{i+1} - t_i,$$

where $s \in [0, 1]$ is the *habit stock* — a simple proxy for past consumption that evolves according to

$$s_{i+1} = (1 - \sigma)s_i + \sigma c_i, \tag{2.6}$$

for some $\sigma \in [0, 1]$. Thus the habit stock at a given decision point is a weighted average of the habit stock and consumption level associated with the previous decision point.[5] Observe $c_i = s_i$ maintains a constant habit stock (i.e. a steady-state). The *speed factor* $\sigma$ captures how quickly the habit changes with consumption.

[5]The form in (2.6) is adapted from Laibson (2001), in which "red" and "green" stock variables evolve only when a cue of their color is present. Thus the red stock does not decay when the green cue appears even though the red habit is not reinforced by consumption. The transition in (2.6) is analogously linked to the next decision, as opposed to a future time, so that a deliberate choice to abstain is needed to weaken the habit. Used for mathematical cleanliness, omitting time from the transition is not essential for the results of the paper.

As a simple benchmark for the basic cravings model, the instantaneous utility function is eliminated:

**Assumption ZP** [Zero Static Consumption Preferences] $u(c) = 0$ *for all* $c$.

Assumption ZP means there are no direct returns to consumption. Instead, chosen consumption matters solely through its influence on the timing of future decisions. Under ZP, the decision opportunity cost is the only payoff parameter — therefore it is never desirable to face a decision.

Cravings are modeled as decision points (i.e. a craving forces the individual to consider consumption). The interval function captures key properties of cravings discussed in the introduction. Letting a subscript denote the associated partial derivative (e.g. $\tau_c = \frac{\partial \tau(s,c)}{\partial c}$), the interval function's basic shape is given by:

**Assumption 1** $\tau : [0,1] \times [0,1] \to \mathbb{R}_{++}$ *is twice-continuously differentiable and satisfies:*

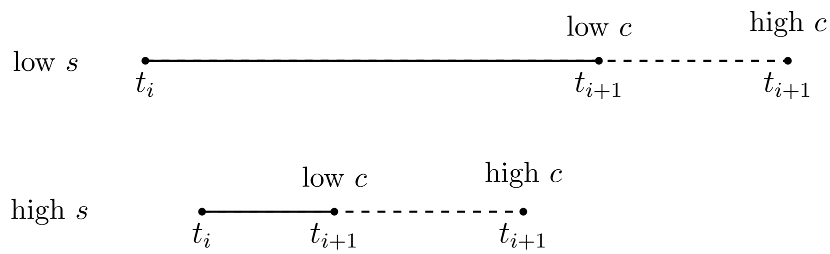
(i) $\tau_s(s,c) < 0$*, for all* $s, c$.

(ii) $\tau_c(s,c) > 0$*, for all* $s, c$.

(iii) $s' > s$ *implies* $\tau(s', s') < \tau(s, s)$.

(iv) $-\delta^{\tau}$ *is strictly concave.*

Part (i) says a larger habit stock entails more frequent decisions, ceteris paribus, which captures the long-run reinforcement of past consumption. Part (ii) says, with $s$ fixed, the interval to the next decision increases with consumption, which captures that consumption alleviates cravings in the short-run. The intervals in the below diagram illustrate the essence of parts (i) and (ii):




Part (iii) of Assumption 1 says if $c = s$ (which holds in a steady-state), then simultaneously increasing both by the same amount decreases the time between decisions, i.e. the interval-shortening effect of $s$ outweighs the lengthening effect of $c$ along the $c = s$ frontier. Therefore, a high steady-state associated with a higher consumption level entails more frequent decisions than a low equilibrium. Concavity of $-\delta^\tau$ from part (iv) implies diminishing returns to consumption. To see why, first note $-\delta^\tau$ is the discounted value of the opportunity cost at the next decision point. Since the sole benefit of consumption under ZP is delaying the next decision opportunity cost, $-\delta^\tau$ can be regarded as the effective return function and its concavity is analogous to diminishing returns through a concave instantaneous utility function — a standard assumption in discrete-time dynamic programming (e.g. Stokey et al., 1989). As with the usual concave instantaneous return function, concavity of $-\delta^\tau$ helps guarantee the existence of a concave value function, given as the fixed point of the Bellman operator from the contraction mapping principle.

### 2.2.1 Dynamic Optimization

Under ZP, dynamic optimization is characterized by the Bellman equation:

$$V(s) = -1 + \max_c \{\delta^{\tau(s,c)} V((1-\sigma)s + \sigma c)\}. \tag{2.7}$$

$V(s)$ is the value function at a decision point with habit stock $s$. At each decision point, the individual pays the decision opportunity cost and chooses consumption to maximize the present value of the next-decision value function. The opportunity cost is placed outside the maximization argument to emphasize its invariance to chosen consumption. Chosen consumption determines the extent of discounting through $\tau$ (where higher $c$ helps), and determines next decision's habit stock in the argument of the future value function (where higher $c$ hurts). The first-order and envelope conditions are:

$$0 = \sigma V'(s_{i+1}) + \ln(\delta)\tau_c(s_i, c_i)V(s_{i+1}), \tag{2.8}$$

$$\text{and} \quad V'(s_i) = \delta^{\tau(s_i,c_i)}[(1-\sigma)V'(s_{i+1}) + \ln(\delta)\tau_s(s_i, c_i)V(s_{i+1})]. \tag{2.9}$$

The superscript $+$ is used to denote the variable or function associated with the next decision and $++$ to denote the next-after-next decision (e.g. $\tau^+ = \tau(s_{i+1}, c_{i+1})$, $\tau^{++} = \tau(s_{i+2}, c_{i+2})$, etc.). Given $s_0$, if an interior solution exists, it is given by the Euler equation:[6]

$$\frac{\sigma\tau_s^+ - (1-\sigma)\tau_c^+}{\sigma\tau_s^+ - (1-\sigma)\tau_c^+ + \tau_c} = 1 + \delta^{\tau^+}\left[\frac{\sigma\tau_s^{++} - (1-\sigma)\tau_c^{++}}{\sigma\tau_s^{++} - (1-\sigma)\tau_c^{++} + \tau_c^+}\right]. \tag{2.10}$$

### 2.2.2 Steady-States

To characterize potential steady-states, define:

$$\mu(s, c) = -\frac{\partial}{\partial c}\left(\frac{\delta^{\tau(s,c)}}{1 - \delta^{\tau(s^+,s^+)}}\right), \tag{2.11}$$

[6] The derivation of the Euler equation is provided in Appendix 2.7.1.

and let $\bar{\mu}(s) = \mu(s, s)$ define the *movement function* (for ZP). The movement function gives the marginal returns to consumption at $c = s$ under ZP, provided the individual consumes exactly the next-decision habit stock at all future decisions. Since the optimization problem is Markovian, if it is optimal to consume $s$ now, then the habit stock permanently remains at $s$. It follows if $s$ is an interior steady-state under ZP, then $\bar{\mu}(s) = 0$. The habit stock rises to the next decision if $\bar{\mu}(s) > 0$ because it is then optimal to consume more than $s$, and falls if $\bar{\mu}(s) < 0$ because it is then optimal to consume less than $s$. Hence, the sign of the movement function indicates the direction the habit stock moves from the current decision to the next under ZP. Equivalently, letting $\tilde{c}(s)$ denote optimal consumption given habit stock $s$, the sign of $\bar{\mu}(s)$ and the sign of $(\tilde{c}(s) - s)$ will agree under ZP.

**Assumption 2**

(i): *$\bar{\mu} : [0, 1] \to \mathbb{R}$ is continuously-differentiable and concave with $\bar{\mu}(0) = 0$, $\bar{\mu}'(0) > 0$, and $\bar{\mu}(1) < 0$.*

(ii): *If $\bar{\mu}(s) = 0$, then: $s' > s$ implies $\mu(s', s) > 0$, and $s' < s$ implies $\mu(s', s) < 0$.*

The $\bar{\mu}(0) = 0$ condition of part (i) essentially defines $s = 0$ as the habit such that zero consumption is "exactly" optimal under ZP — i.e. $\tilde{c}(0) = 0$ independent of the fact that zero is the lower bound of $c$'s domain, the unit interval. Thus Assumption 2 ensures a zero-consumption steady-state at $s = 0$. The next condition, $\bar{\mu}'(0) > 0$, implies optimal consumption exceeds the habit stock for sufficiently small $s > 0$. The final condition, $\bar{\mu}(1) < 0$, implies optimal consumption is less than the habit stock at the maximum habit. In addition to the zero-consumption steady-state, part (i) of Assumption 2 helps establish a unique, interior steady-state since concavity of $\bar{\mu}$ ensures there is one nonzero habit for which $\bar{\mu}(s) = 0$.[7]

Part (ii) of Assumption 2 captures the idea that the extent to which consumption delays a craving is greater at a higher habit (and smaller at a lower habit). That is, if $s'$ is an interior steady-state under ZP and the actual habit stock $s$ is less than $s'$, then returns from $c = s'$ are lower at $s$ than at $s'$, which implies optimal consumption is less than $s'$ (conversely, if $s > s'$, returns from $c = s'$ are greater than at $s'$). Assumptions 1 and 2 are maintained throughout the paper.[8]

**Proposition 7** [Addicted Steady-State] *Under ZP, there is a unique* $s^* \in (0, 1)$ *such that* $s_i$ *converges to* $s^*$ *if and only if* $s_0 > 0$.

All proofs are in the Appendix. Proposition 7 establishes a *stable* steady-state of addiction $s^*$, where the habit stock converges to $s^*$ for any $s_0 > 0$. If $s_0 = 0$, the individual remains at the (unstable) zero-consumption steady-state. The stability of $s^*$ and instability of the zero-consumption steady-state jointly represent a drastic case where addiction becomes inevitable with any small deviation from $c = 0$. This reflects the "slippery slope" nature of addiction, as an individual can readily fall into its trap, while escape is difficult. Behavior of an addict is defined by the steady-state consumption level $c^* = s^*$ and by the intervals between consumption occasions, $\tau^* = \tau(s^*, s^*)$. Relative to the addicted steady-state, consumption is less frequent at any $s < s^*$,

[7] Concavity is a stricter than necessary assumption to get single-crossing, but it will be useful in later sections.

[8] A parametric example that satisfies Assumptions 1 and 2 is provided in Appendix 2.7.2.

and more frequent at any $s > s^*$.[9] This characterization of habit strength in terms of the frequency of consumption fits with standard notions in the social sciences (Ouellette and Wood, 1998; Verplanken, 2006).[10]

### 2.2.3 Harmful Consumption and "Chippers"

Unaccounted for by ZP, the direct costs of tobacco consumption have grown.[11] The rise in costs has coincided with the rise of *chippers*, a class of low frequency users who comprise nearly 40 percent of U.S. smokers.[12] To account for direct costs, let $\theta \geq 0$ denote a direct cost parameter. Express instantaneous utility as $u(c|\theta)$ with the normalization $u(0|\theta) = 0$, for all $\theta$, where it is presumed $\theta = 0$ corresponds to ZP so that $u(c|0) = 0$, for all $c$. Now consider the alternative to ZP:

**Assumption NP** [Negative Static Consumption Preferences] *Direct costs are nonzero,* $\theta > 0$*, where the instantaneous utility function* $u : [0,1] \times \mathbb{R}_+ \to \mathbb{R}$ *is twice continuously differentiable and strictly concave, with* $u_c < 0$ *(provided* $\theta > 0$*) and* $u_{c\theta} < 0$*.*

[9] Lower frequency holds for $s < s^*$ because $\tau(s^*, s^*) < \tau(s, s) \leq \tau(s, \tilde{c}(s))$ (where the last inequality is strict unless $s = 0$). Higher frequency holds for $s > s^*$ because $\tau(s^*, s^*) > \tau(s, s) > \tau(s, \tilde{c}(s))$.

[10] Still, the cited studies suggest the standard frequency definition is an incomplete psychological representation since behavior often becomes automatized as habits develop. The automatization of choices, which reduces (but does not eliminate) their toll on decision-making faculties, likely means there is gray area in classifying a "decision." (If a "choice" is performed automatically without deliberation, is it preceded by a decision?) The distinction between automatized and non-automatized behavior relates to Bernheim and Rangel's (2004) addiction model, in which the decision-maker consumes automatically (and mistakenly) in a "hot" state, but chooses rationally in a "cold" state.

[11] Since the 1960s, several costs and restrictions have proliferated — e.g. new taxes, better information regarding health risks, the emergence of a social stigma, and bans on smoking at work or in public areas. See Becker et al. (1994), Chaloupka and Warner (2000).

[12] See Shiffman (2009) for a helpful primer on chippers. The 40 percent figure is based on a recent Health and Human Services survey (Substance Abuse and Mental Health Services Administration, 2010). While the survey does not use the term "chipper," the statistic holds for the usual definition of chippers as nondaily smokers.

With NP, consumption is directly harmful in that the instantaneous utility function is negative and decreasing.[13] Throughout the paper, results for NP will generally hold as long as consumption preferences aren't "too negative," i.e. for a range of small, positive $\theta$. Therefore, in subsequent results, the phrase "under NP" is used as shorthand for "there is a $\bar{\theta} > 0$ such that $\theta \in (0, \bar{\theta})$ implies the following results hold under NP." This implicit qualifier reflects the notion that if direct costs are too large, then the individual will never consume (and analyzing "behavior" in this scenario is an empty endeavor).

**Proposition 8** [Trimodality] *Under NP there are three steady-states,* $\{0, s_L^*, s_H^*\}$, *where* $s_i$ *converges to zero iff* $s_0 < s_L^*$*, and* $s_i$ *converges to* $s_H^*$ *iff* $s_0 > s_L^*$*.*

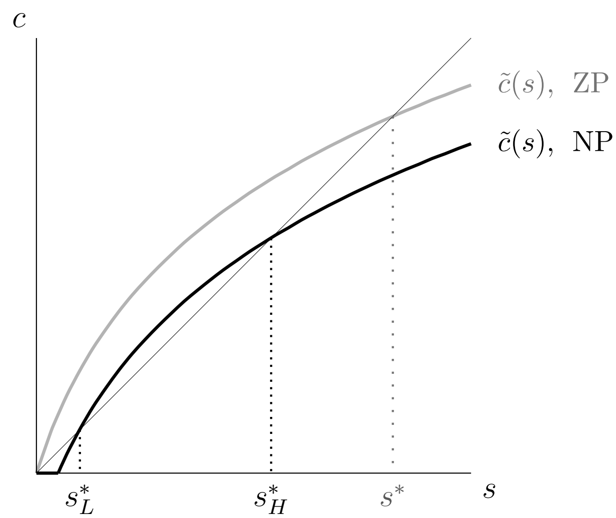
Thus integrating a small direct cost generates a third "ambivalent chipper" steady-state, $s_L^*$, illustrating the emergence of *trimodality*, a distribution of consumption with three modes.[14] The instability of this intermediate steady-state qualitatively captures evidence, as a chipper's position is highly unstable compared to nonsmokers and heavy smokers (Zhu et al., 2003). Now we don't want to think of real-life chippers as existing exactly at the steady-state, but instead in its vicinity, where the ambivalent chipper sits perfectly on the fence

[13] As NP consolidates *direct* returns from present consumption to $u(c)$, NP is still an idealization since actual direct returns likely involve an immediate benefit and a larger, future cost. Consolidation of present and future returns with $u'(c) < 0$ means direct costs must outweigh the benefits of consumption, so future costs cannot be diluted by sufficiently steep impatience (low $\delta$) to "rationalize" consumption. Also note, with time-consistent discounting and time-separable utility the consolidation has no effect on optimizing behavior.

[14] The notion that the prominence of chippers rises with $\theta$ is clear when direct costs increase from $\theta = 0$ because chippers do not exist under ZP. While not as obvious, the interpretation remains valid for $\theta > 0$. First, as $\theta$ continues to increase, so does $s_L^*$, making it harder to justify a bimodal characterization that implicitly lumps chippers with abstainers at a steady-state in the vicinity of zero. Second, the range of $s_0$'s such that $s$ converges to zero in the long-run widens; hence, we would expect the prevalence of users to fall, and consequently the prominence of chippers to rise relative to addicts.

between quitting and becoming an addict in the long-run.[15]

The figure below shows how optimal consumption may look before and after replacing ZP with NP:



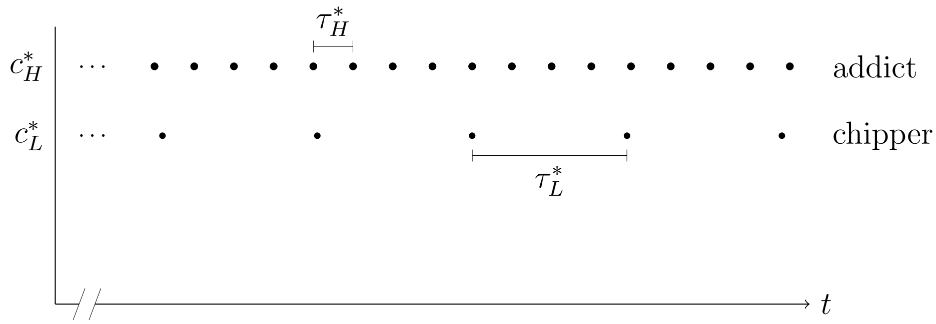

As before, NP gives a zero-consumption steady-state at $s = 0$, but it is now stable so small deviations no longer lead to addiction.[16] The high steady-state, $s^*_H$, is the addicted steady-state under NP, analogous to $s^*$ under ZP. The position of the low steady-state, $s^*_L$, suggests chippers may signify a rough "threshold" for addiction — an idea proposed by medical researchers (Benowitz and Henningfield, 1994).

The chipper's behavior is characterized by the consumption level $c^*_L = s^*_L$ and the intervals $\tau^*_L = \tau(s^*_L, s^*_L)$, while the addict is described by $c^*_H$ and $\tau^*_H$,

[15] Although $s^*_L$ does not attract a significant population share in the long-run, an individual who starts near (but not at) $s^*_L$ may remain nearby for a long time because habits move slowly when close to a steady-state — if many chippers are only "approximate" chippers, then the likelihood a smoker is classified as a chipper will decrease with age, which turns out to be true, as a smaller share of older smokers are chippers than younger smokers (Hennrikus et al. 1996; Wortley et al., 2003).

[16] Stability of $s = 0$ under NP follows because while assumption 2 is retained, the interpretation of $\bar{\mu}$ holds only for $\theta = 0$; $\bar{\mu}(0) = 0$ with $\theta > 0$ overestimates the marginal return from $c = 0$ at zero habit stock.

as illustrated below:




Each dot here represents a single instance of consumption. The lower height of chippers' dots indicates they have lower steady-state consumption levels than addicts, and the longer intervals between neighboring dots indicate chippers consume less frequently than addicts. This dual level-frequency characterization of habit strength is needed to capture empirical findings: while the frequency aspect is tautological (chippers are defined as "occasional smokers") consumption levels diverge too, as addicts inhale more nicotine per cigarette than chippers (Shiffman, 1989).

### 2.2.4 Principal "Macroscopic" Features of Addiction

Drawing on evidence from disparate fields, BH-C highlights four principal *macroscopic* features of addiction through an economic lens: (i) addiction is "bad," (ii) addiction involves forward-looking optimization, (iii) opportunity costs are a main driver of addiction, and (iv) addictive demand exhibits adjacent substitution (with distant complementarity). "Macroscopic" in that they are *not* contingent on knowing the timing of decisions, the four features facilitate comparisons to prevailing representations of bad habits, which are cast in standard time.

Properties (i)-(iii) are inherent in the model's specification under ZP. Addiction is bad because it entails frequent payments of the decision opportunity cost. The notion that addiction can be bad simply by being a waste of time is a novel feature of the model.[17] Forward-looking optimization and opportunity costs as the key driver hold by construction, where the emphasis on opportunity costs is a unique trait of the model. Property (iv), adjacent substitution (with distant complementarity), requires elaboration.

## 2.3 Intertemporal Substitution and Inference

### 2.3.1 Demand: Frequency and Level of Consumption

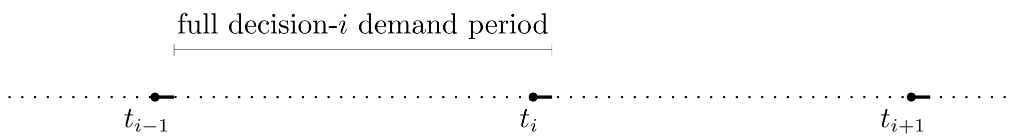
Adjacent substitution means demand in the "adjacent" future increases with current consumption. In a standard, discrete-time setting, the relevant demand measure is consumption in the next decision period. However, because the intervals between decisions vary endogenously, next decision's consumption level is an inconsistent standard in the current framework. Since demand ought to reflect how much and how often one consumes, a time-averaged consumption rate is a natural measure. *Decision-$i$ demand* is denoted by $x(i)$ and defined as the mean consumption rate during the union of decision $i$'s 'active' and 'latent' periods:[18]

[17]While the underlying reasons and mechanisms differ, ZP captures a *harmful* addiction in the traditional sense of Stigler and Becker (1977), as well as Becker and Murphy (1988), in that a higher stock of past consumption implies lower future utility, i.e. $V'(s) < 0$. NP, however, motivates addiction under a stronger conception of "harmful" than previous treatments in that consumption is directly costly too, i.e. $u'(c) < 0$ and $V'(s) < 0$.

[18]That is, decision-$i$ demand is decomposed as the active demand during the consumption period starting at $t_i$ and the latent demand during the latency period ending at $t_i$. The term "latent demand" is borrowed from Morgenstern's (1948) description of interim demand as "latent" for a consumer who must wait until a particular future time to purchase goods.

$$x(i) = \frac{c_i}{\tau(s_{i-1}, c_{i-1})}.$$

Inspecting the diagram below, it's seen $\tau(s_{i-1}, c_{i-1})$ is the appropriate time-window, where the dotted lines represent latent demand periods and the solid segments are active demand periods:




For the current treatment, with a negligible pause length, the full demand period for decision $i$ is $(t_{i-1}, t_i]$.

*Adjacent substitution* holds if next-decision demand falls with current consumption: $-\frac{\partial x(i+1)}{\partial c_i} > 0$, where the left-side of the inequality is the *marginal rate of adjacent substitution* (MRAS), which reflects the degree of substitutability between the good now and the good in the immediate future. *Adjacent complementarity* holds if MRAS is negative (i.e. the good now and in the immediate future are complements). MRAS' sign is ambiguous at the outset — consumption extends the interval, but may also increase the next-decision consumption level. That said, as follows from $\frac{\partial c_{i+1}}{\partial c_i} = \sigma \frac{d\tilde{c}(s_{i+1})}{ds_{i+1}}$, the interval-extending effect dominates if the speed factor $\sigma$ is sufficiently small, which would guarantee adjacent substitution.

### 2.3.2 Interval-Driven Adjacent Substitution

The next result shows how addicts in identical steady-states (i.e. same $c^*$ and $\tau^*$) with the same interval function can be parametrically different:

**Proposition 9** [Comparing Addicts]: *Under ZP, consider the addicted steady-state* $(c^*, \tau^*)$ *that exists given the interval function* $\tau$*, with discount and speed factors* $\delta$ *and* $\sigma$*. Take any* $\sigma' \in (0,1)$ *and define:*

$$\delta' = \left[1 - \sigma' \left(\frac{\partial \tau(c^*, c^*)/\partial s}{\partial \tau(c^*, c^*)/\partial c} + 1\right)\right] \tag{2.12}$$

*Then* $(c^*, \tau^*)$ *is the addicted steady-state given* $\tau$*,* $\delta'$*, and* $\sigma'$*.*

"Different" addicts with the same interval function can be in the same steady-state because steady-state behavior does not pin down all model parameters. Equation (2.12) allows us to compare two such addicts. Observe that a more patient (higher $\delta$) addict has a habit that adjusts slower to consumption (lower $\sigma$), which follows because both the discount and speed factors dampen the long-term costs of consumption. Accommodating realistic and "rational" parameterizations of patience, Proposition 9 implies that the addicted steady-state exists for $\delta$ arbitrarily close to one.[19] Further, since MRAS$> 0$ for sufficiently small $\sigma$, adjacent substitution is assured for a range of $\delta$ that includes the most patient addicts:

**Corollary 2** [Adjacent Substitution]: *Under ZP, given the same* $(c^*, \tau^*)$ *and* $\tau$ *from Proposition 9, there is a* $\bar{\delta} < 1$ *such that* $\delta \in (\bar{\delta}, 1)$ *implies there is a corresponding* $\sigma \in (0,1)$ *for which the steady-state* $(c^*, \tau^*)$ *exists given* $\tau, \delta, \sigma$*, and adjacent substitution is satisfied.*

[19] A caveat: near-perfect patience comes hand-in-hand with a colossally slow habit stock. A caveat to the caveat: in the present construction, consumption has no persistent, positive effect beyond the next decision point. This was a simplification to obviate the need for multiple state variables. By incorporating persistence to the short-term effect of consumption, a given $\delta$ could coexist with a faster habit stock, all else equal.

Since the interval-extending effect of consumption is the basis for MRAS $>$ 0, Corollary 2 establishes *interval-driven* adjacent substitution. The interval-driven aspect captures the incentive to consume and also embeds an unusual depiction of commitment: by delaying the next opportunity to consume, *consumption* is a valuable short-term commitment strategy to restrict future consumption. Because avoiding a decision point allows the individual to engage outside opportunities, commitment and flexibility arrive in tandem — a contrast to the usual treatment in which they are opposites, characterized by constricted or expanded choice sets. This *decision*-level characterization of commitment reflects the fact that a neglected craving is an ongoing drain on decision-making faculties, and decision-level commitment is inherent in any approach — such as wearing a nicotine patch — that eliminates or postpones cravings.

Adjacent substitution bucks convention, as adjacent complementarity is the definition of addiction in the preeminent rational addiction theory of Becker and Murphy (1988) based on habit-formation preferences.[20] The standard tool in economics for modeling habits, *habit-formation preferences* are represented by a time-inseparable utility function in which past consumption enters today's return, e.g. $u(c, s)$, where $u_c > 0$ and $u_{sc} > 0$ are presumed.[21] Adjacent

[20]Although many alternatives to rational addiction have been proposed, there have been no serious objections to adjacent complementarity. That said, updates to the original rational theory have accounted for important phenomena unexplained by habit-formation preferences alone, such as learning and regret (Orphanides and Zervos, 1995), the demand for commitment mechanisms (Gruber and Kőszegi, 2001), and stochastic environmental cues (Laibson, 2001). Recent treatments of addiction that do not employ habit-formation preferences include Gul and Pesendorfer's (2007) model, which accounts for commitment through preferences that depend on an unchosen alternative of the choice set.

[21]Habit-formation preferences are the prototype of *time-inseparability* (history-dependence). As Pollak (1970) describes his seminal habit hypothesis: "(i) that past consumption influences current preferences and hence, current demand and (ii) that a higher level of past consumption of a good implies, ceteris paribus, a higher level of present consumption." Time-inseparable prefer-

complementarity is a manifestation of habit-formation preferences because the marginal utility of consumption rises with past consumption.

### 2.3.3 Measurement and Inference in Discrete-Time

This sections considers a simple discrete-time empirical analysis of behavior from endogenous decision points, allowing us to compare the model to prevailing treatments of bad habits in a common temporal framework. As choices are typically aggregated into metronomic bins in empirical work, the exercise will also help to distinguish what traditional discrete-time inference can and cannot tell us when the timing of decisions varies endogenously.

Consider a discrete-time demand analysis (presuming the decision points model is the data generating process), where $\ell$ is the fixed measurement period length, and $T_n$ is the time measurement period $n$ ends. Then *measured demand* for measurement period $n$, denoted as $C_n$, is the average demand during the measurement period:[22]

$$C_n = \frac{1}{\ell}\int_{T_n-\ell}^{T_n} x(i : t_{i-1} < t \leq t_i)dt.$$

Accordingly, *measured adjacent substitution* is defined using a typical discrete-time notion: $-\frac{\partial C_{n+1}}{\partial C_n} > 0$, which implies substitutability between consecutive measurement periods, i.e. the *measured* MRAS is positive.[23] Per usual, *mea-*

ences continue to be central in the extensive habit-formation literature that followed — including Rozen's (2010) axiomatization and Crawford's (2010) revealed-preference empirical treatment of time-inseparability.

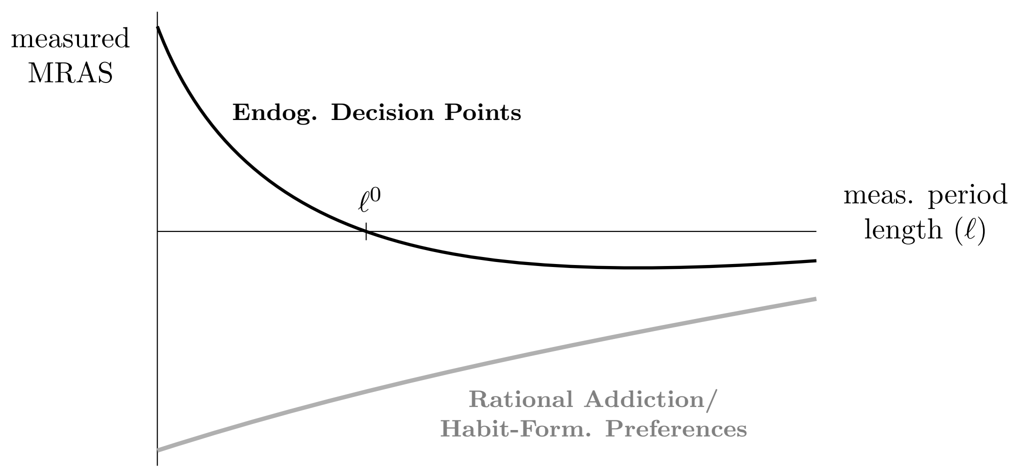
[22]Implicit in this formulation is that the flow demand is constant over each decision's demand period. This "flattening" allows a continuous measure of $C$. If the relevant instant associated with decision-$i$ demand is the time of the purchase for consumption at $t_i$, the specification can be motivated by assuming the purchase is equally likely to occur at any time in $(t_{i-1}, t_i]$.

[23]As is, the denominator of the measured MRAS is not well defined because there are multiple ways to "perturb" demand in $n$ if the measurement period contains multiple decisions. Qualita-

*sured adjacent complementarity* holds if the inequality is reversed.

**Proposition 10** [Measured Substitution Threshold]
*Given adjacent substitution holds, there is a $\ell^0 > 0$ such that an addict's demand exhibits measured adjacent substitution if $\ell < \ell^0$ (and measured adjacent complementarity if $\ell > \ell^0$).*

Thus if the measurement period length exceeds a threshold, addictive behavior falsely appears to satisfy adjacent complementarity — a reflection of *distant* complementarity. Below the threshold, adjacent substitution is detected. The result shows how the decision points model is distinguishable from rational addiction and habit-formation preferences even in standard time, with sufficiently high-resolution data. The qualitative relationship between measured intertemporal substitution and data resolution is shown below:




While a helpful start, measured adjacent substitution masks the richer de-

tively, it will not matter for the results whether the perturbed demand is at the beginning of the measurement period, at the end, or at some fixed fraction in between. Therefore, for simplicity and without loss of (qualitative) generality, assume perturbed consumption is at the end of the measurement period, so that measured adjacent substitution can be expressed as $-\frac{\partial C_{n+1}}{\partial x(i)}$ where $t_i = T_n$.

scription given by interval-driven adjacent substitution. Because discrete-time cannot detect endogenous intervals (and decision opportunity costs), measurement conceals the incentive to consume — regardless of dataset resolution. This is not a trivial omission considering the substantial theoretical interest in addiction largely stems from the challenge of explaining *why* a rational agent would consume harmful addictive products.

### 2.3.4 Inferring Preferences with "Omitted Decision Point" Bias

Empirical analyses generally seek to understand observed behavior in terms of economic primitives. Hence, as a natural next step, preferences are "inferred" using the misspecified measurement framework. Given the incentive is concealed in standard time, the inferences will help us understand how harmful addictions are rationalized in metronomic models. The procedure will "reveal" both static consumption preferences and time preferences, i.e. discounting. As will be addressed, BH-C documents two departures from constant discounting that are prominent in addiction research: (i) *commodity-dependence*, as addicts appear exceedingly impatient to consume drugs, discounting future drugs much steeper than future money; and (ii) *endogenous time-preference*, as drug use appears to improve short-run patience and lessen patience in the long-run.[24]

As a conventional approach to infer preferences, consider a contemporaneous payoff function $U^{+}(C)$ and a decreasing future loss function $U^{-}(C)$ where $C$ is demand in the current measurement period. For ease of exposition (and without loss of generality), the future loss occurs one time-unit after the payoff.

[24]The long-horizon form is inherent in theories of endogenous time preference in which addictive consumption steepens impatience (Becker and Mulligan, 1997; Orphanides and Zervos, 1998).

Thus the composite return is:

$$U(C|\delta) = U^+(C) + \delta U^-(C).$$

This form reflects the usual contention that addictive consumption entails present benefits and future costs (beyond the indirect costs of habit reinforcement). Now suppose, with the true discount factor $\delta$, the composite return accurately represents time-aggregated static consumption preferences.[25] Then $U(C_n|\delta)$ is any positive affine transformation of

$$\int_{T_n-\ell}^{T_n} \left[ \frac{\delta^{t_i} u(c_i)}{t_i - t_{i-1}} : t_{i-1} < t \leq t_i \right] dt.$$

That is, with the correct $\delta$, the composite return over time-aggregated demand is equivalent to the true time-aggregated direct returns from demand in the measurement period. Based on the known payoff and future loss functions, the *measured discount factor* for period-$n$, denoted by $\hat{\delta}_n$, is calculated from the empirical utility maximization problem:

$$\hat{\delta}_n = \{\delta_n : C_n = \arg\max_C \; U(C|\delta_n)\}.$$

Thus the measured discount factor is the discount factor for which observed demand appears to maximize utility. In turn, the *measured marginal utility of*

[25]As used here, *static* consumption preferences means the choice is considered in isolation from all future choices and thus reflects only the direct costs of consumption. The results derived from this specification are robust to inclusion of a future value term (along with $U^-(C)$) to account for indirect costs. A future value term is omitted for simplicity and also to adhere to common practice, as measured discount rates typically do not account for habit reinforcement (Frederick et al., 2002).

*consumption* can be computed for any demand level as

$$U'(C|\hat{\delta}_n) = U^{(+)'}(C|\hat{\delta}_n) + \hat{\delta}_n U^{(-)'}(C|\hat{\delta}_n),$$

which characterizes the shape of the individual's apparent consumption preferences under time-aggregation.

The next result shows how ignoring decision points can account for observed constant discounting departures, while shedding light on the inference of consumption preferences when "time" is misspecified.

**Proposition 11** *Under NP, assume $U^+$ and $U^-$ are both weakly concave.*
(i-a) [Impatience for Good] $\hat{\delta}_n < \delta$, *provided* $C_n > 0$.
(i-b) ["False Positive" Preferences] $U'(C|\hat{\delta}_n) > 0$ *for all* $C \in [0, C_n]$.
*Given adjacent substitution holds for an addict:*
(ii-a) [Endogenous Time-Preference] $\hat{\delta}_{n+1}$ *decreases with* $C_n$ *if* $\ell > \ell^0$, *and increases with* $C_n$ *if* $\ell < \ell^0$, *where* $\ell^0$ *is the substitution threshold in Proposition 10.*
(ii-b) [Time-Inseparable Consumption Preferences] *For any* $C \geq 0$: $U'(C|\hat{\delta}_{n+1})$ *increases with* $C_n$ *if* $\ell > \ell^0$, *and decreases with* $C_n$ *if* $\ell < \ell^0$.

Part (i-a) shows how consumption is justified by excessive impatience for the good, which reconciles commodity-dependence since the estimate is less than the true $\delta$ (presumably measurable from outside choices). Consequently, positive consumption preferences are inferred in part (i-b), as future costs are seemingly neglected. Part (ii-a) captures both long- and short-run forms of endogenous discounting. Estimated patience falls with consumption in the previous measurement period if the period length is too large to detect adjacent substitution (otherwise, estimated patience rises). Because the discount factor enters the composite return, time-inseparable consumption preferences are naturally inferred in part (ii-b), in that the measured marginal utility of consumption is affected by past demand.[26] The more "noticeable" long-term effect (for long measurement periods), arises due to habit reinforcement, and appears to reveal a consumption preference that grows with the habit — i.e., coupled with part (i-b), as revealing habit-formation preferences.

The irregular discounting patterns and habit-formation preferences of Proposition 11 reflect *omitted decision point bias.* That is, the measurement framework is misspecified because intervals are exogenously fixed, and to compensate, the estimation attributes decision-point influences to the discount and utility functions. The impatience-based rationalization of positive consumption preferences — a reversal of the underlying NP specification — resembles the rational addiction approach, which employs steep discounting to dilute future harmful effects of present consumption.[27] The characterization of habit-formation preferences as an artifact of misspecification has neuropsychological backing, as researchers find drugs are increasingly 'wanted' despite not being increasingly 'liked' in the course of addiction.[28] Given that "revealed" preferences under discrete-time aggregation diverge from true preferences, it may be

[26]Apparent time-inseparability can also arise if, instead of taking $U^+$ as known and estimating $\delta$, any $\delta > 0$ is presumed (whether correct or incorrect) and the form of $U^+$ is inferred.

[27]As Becker and Murphy (1988) explain: "this paper relies on a weak concept of rationality that does not rule out strong discounts of future events." This reliance is understandable in light of standard time's exogenous decision schedule, as metronomism imposes a bound of sorts on rationality in that decision-makers are granted no control over the timing of their own decisions. In this vein, endogenous decision points provides an added channel for optimization, which (as seen) permits a representation of harmful addiction with negative consumption preferences and a discount factor arbitrarily close to one (Proposition 10).

[28]The liking-wanting gap is a centerpiece of the incentive-sensitization addiction theory of Robinson and Berridge (1993). See BH-C for additional background and discussion.

fruitful to collect real time data, to develop econometric techniques to tease out micro time structures, or to look more at time use surveys to account for decision-point effects in empirical research on habits and addictions.

## 2.4 External Cues

Exposure to an item or context associated with a behavior can act as a powerful impetus to do the behavior. For addiction, the significance of such external *cues* (e.g. an offer of a cigarette or the sight of an ashtray) is widely documented in psychology. This line of research has motivated economic cues models by Laibson (2001) and Bernheim and Rangel (2004). While the precise economic representation of a cue varies from model to model, stochasticness is a shared feature because cues introduce variance in consumption patterns (and long-term outcomes), as use is linked to seemingly random environmental factors.

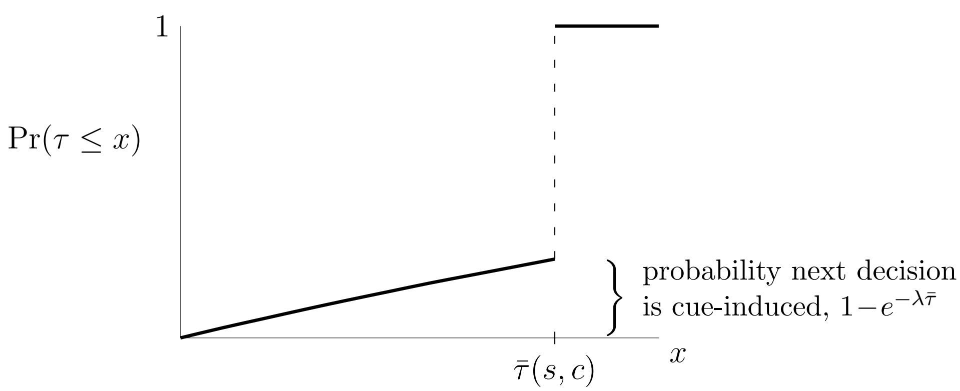
Although it can be difficult to differentiate a cue from a craving in isolation, a clear contrast emerges when comparing their roles across the habit spectrum.[29] That is, stochastic factors (i.e. external cues) are germane at low levels of dependence, yet deterministic forces appear to dominate in the realm of heavy addiction. A trademark of strong nicotine dependence is inflexible smoking patterns largely *uninfluenced* by environmental cues (Shiffman et al., 2004). Accordingly, consumption is more strongly associated with external cues for chippers than for addicts (Shiffman and Paty, 2006); this pattern "significantly distinguishes" addicts from light-use chippers (Shiffman and Sayette,

[29]Since external cues can elicit internal cravings, to avoid confusion, I use "craving" to refer to an urge with an internal origin and "cue" to refer to an urge with an external origin.

2005).

### 2.4.1 Cues as Decision Points

The influence of a single cue is reminiscent of an internal craving: when a cue arises, the urge to consume suddenly materializes. In light of the similarities, external cues are modeled as (stochastic) decision points. As a simple baseline, assume cues have a fixed arrival rate $\lambda > 0$.[30] The deterministic element (cravings) is retained from the original model with the "natural" interval function $\bar{\tau}$, which is the time until the next decision if there is no cue in the interim. The true interval $\tau$ is now an exponential random variable parameterized by $\lambda$ and right-censored at $\bar{\tau}$. The cumulative distribution function of $\tau$ is illustrated below:




The following lemma establishes an equivalence between the original, deterministic model and the new setup that combines stochastic cues with internal cravings.

[30]Two notes on fixed $\lambda$: first, the fixed arrival rate treats the duration of the interruption as negligible. Second, there are reasons to expect the true cue event-rate varies with $s$ and $c$, e.g. smokers are likely exposed to smoking situations more often than nonsmokers. The results of the section are robust to an endogenous cue-arrival rate, provided its curvature is weak relative to the interval function's.

**Lemma 1** *Consider the stochastic cues model described above with arrival rate $\lambda$ and natural interval function $\bar{\tau}$. Define*

$$\tau^0 = \frac{\ln\left[\left(\lambda - e^{-\lambda\bar{\tau}}\ln(\delta)\delta^{\bar{\tau}}\right)/(\lambda - \ln(\delta))\right]}{\ln(\delta)}.$$

*Then, given $s_0$, the optimal consumption sequence $(c_0, c_1, \ldots)$ with stochastic cues is the same as in the deterministic setting with the interval function $\tau^0$.*

Lemma 1 defines $\tau^0$ as a "certainty equivalent" for the random interval function $\tau$, in that the optimization problem with stochastic cues is the same as in the cravings-only model using $\tau^0$. That is, at a decision point, the expected future value with cue-arrival rate $\lambda$ and natural interval $\bar{\tau}(s, c)$ equals the known future value with $\tau^0(s, c)$, for all $s, c$. The lemma allows us to carry over previously-derived steady-states to the cues setting.[31] Hence steady-state terminology ("addicts" and "chippers") is maintained with the understanding that the corresponding habit stocks are those that would exist in the original model using $\tau^0$.

### 2.4.2 External Cues: Diminished Role under Addiction

The next result compares the importance of stochastic cues between addicts and chippers.

**Proposition 12** *The following are smaller for addicts than for chippers, ceteris paribus:*

(i) *the share of consumption that coincides with a stochastic cue.*

[31] As before, $s_{i+1} = (1 - \sigma)s_i + \sigma c_i$ regardless of whether $t_{i+1}$ is craving-induced or cue-induced. This assumption simplifies the dynamic optimization problem (otherwise, the deterministic equivalence is lost).

(ii) *the variance of* $\tau$.

Proposition 12 implies that consumption schedules are less random and less associated with stochastic cues for addicts than for chippers, which holds because internal cravings are more frequent for stronger habits. The result matches the evidence that addicts have consistent, regimented patterns of drug use, while the influence of cues is more pronounced for chippers, who have less predictable consumption routines.[32] Proposition 12 is robust to a degree of habit stock dependence in the cue-arrival rate — e.g. the addict may have a smaller share of consumption coinciding with a cue even if the addict's arrival rate exceeds the chipper's, $\lambda(s_H^*) > \lambda(s_L^*)$.[33]

The current treatment contrasts the emphasis on random external factors in recent cue-based economic theories. In Bernheim and Rangel's (2004) model, the path to addiction is marked by an escalating vulnerability to stochastic environmental cues. This runs counter to the evidence that consumption becomes predominantly driven by internal cravings as addiction develops, as the intervals between doses become shorter and more predictable.

The next proposition further deemphasizes the importance of stochastic cues for understanding behavior under addiction.

**Proposition 13** [Cue-Flooding]: *Fix* $\theta > 0$ *given NP. There is a* $\bar{\lambda} > 0$ *such that* $\lambda > \bar{\lambda}$ *implies* $\tilde{c}(s) = 0$ *for all* $s$.

[32]The variance of the consumption frequency, $\mathrm{Var}[\tau^{-1}]$ is not defined, but it would also be negatively correlated with habit strength in the continuous limit under a discretization of time units. By contrast, for a cues-only model in which the cue frequency is an increasing function of the habit stock, $\mathrm{Var}[\tau^{-1}]$ is positively correlated with habit strength for realistic values of the arrival rate. See Appendix 2.7.11 for details.

[33]We can use the formula in Lemma 1 to define $\tau^0$ from an endogenous cue-arrival rate, $\lambda(s, c)$, and $\tau^0$ will still be a function of $s$ and $c$ only. Lemma 1's proof does not require fixed $\lambda$, hence the "certainty equivalent" interpretation of $\tau^0$ remains valid and analysis can proceed as it would with fixed $\lambda$.

Abstinence is optimal for sufficiently high cue-arrival rates because rapidly-arriving cues undercut interval-driven adjacent substitution, washing out the incentive to consume. For instance, one could raise consumption from zero to some $c > 0$ to elongate the natural interval to $\bar{\tau}(s, c) > \bar{\tau}(s, 0)$, but a cue's arrival prior to $\bar{\tau}(s, 0)$ negates the benefit of a longer natural interval. Proposition 13 pertains specifically to exogenous cues, as the individual's helplessness against the onslaught of cues is the basis for abstinence. While a randomly-arriving cue may often come and go regardless of the individual's choice, the next subsection describes how a special type of cue can feature a pronounced form of endogeneity, which gives rise to starkly different implications than exogenous cues for behavior and long-run outcomes.

### 2.4.3 The Good as a Persistent Cue

The motivational force of a cue is commonly attributed to the notion that cues signal *availability* of the good.[34] Therefore, the *good* itself ought to be a cue. Presuming unconsumed quantities do not perish, a modification is needed to represent the good as a cue because cues come and go regardless of the choice in the existing setup. To incorporate its persistence, suppose $a(t)$ is the amount of the good that is immediately accessible at $t$ and $\lambda^a > \lambda$ is the cue-arrival rate at all $t$ with $a(t) > 0$, where $\lambda$ now denotes the arrival rate when the good is not immediately accessible. If the amount of the good at some decision point is positive and slightly greater than the "usual" optimal consumption level (without the good as a cue), then it is optimal to consume all of the good: $c_i = a(t_i) > \tilde{c}(s_i)$, where $\tilde{c}$ is maintained as the optimal consumption

[34] The importance of availability in cue effectiveness is addressed by Droungas et al. (1995), Juliano and Brandon (1998), and Carter and Tiffany (2001).

function without cue-persistence. Access to the good creates an imperative to raise consumption because the unconsumed good invites a heightened arrival rate, from $\lambda$ to $\lambda^a$.[35]

Because its persistence motivates higher than usual consumption, access to the good can precipitate undesirable long-run outcomes. For instance, addiction becomes inevitable for an otherwise ambivalent chipper who consumes $a > s^*_L$, or even for a "recovering" user on the path to abstention with $s < s^*_L$, provided $(1-\sigma)s + \sigma a > s^*_L$. These observations fit with evidence that the physical presence of the good often drives smoking and alcohol relapses (Niaura et al., 1988). Furthermore, the incentive to consume no longer relies on the "soft persistence" of internal cravings, which is consistent with the finding that cigarette cues undercut the effectiveness of nicotine replacement therapies that inhibit internal cravings.[36] Because immediate access to large quantities is especially burdensome, the good as a decision point also offers a rationale for the common practice among smokers of buying packs instead of cartons as a commitment strategy (Khwaja et al., 2007).

## 2.5 Group Behavior

Economists use "social interactions" models to capture the observation that individuals within a group tend to act alike. Group smoking behavior —

[35]The concept parallels Fudenberg and Levine's (2012) consideration of persistent temptations. In their model, an agent suffers a continual cost from the availability of a persistently tempting good (until it is gone). Consequently, it is "easier to resist" a fleeting temptation than a persistent temptation.

[36]In Waters et al. (2004), abstinent smokers randomized to a nicotine patch or a placebo were given a cigarette and instructed to hold it as if they were between puffs. The patch lowered the baseline urge to smoke, but it did not attenuate the spike in the urge from holding the cigarette. As the authors write, "abstinence-related urges and cue-provoked urges may have different origins and might be treated differently."

often called *peer effects* in this realm — is an active area of social interactions research. The traditional econometric evidence of peer effects is that an individual's propensity to participate in the behavior rises with the use or prevalence among others in the peer group. BH-C identifies three key patterns from addiction research underlying the propensity measure: (i) *synchronization*, as smokers tend to consume in unison with others; (ii) *self-sorting*, as individuals tend to select into groups with similar characteristics; and (iii) *herd behavior*, as individuals tend to adopt the same behaviors as their peers.

### 2.5.1 Peer Consumption as a Decision Point

Because it is a type of cue, peer consumption is modeled as a decision point. As in the cues setting, $\bar{\tau}$ is the natural interval function, which now gives the time from the current to the next decision if no peers consume in the interim. Let a superscript $j$ correspond to an individual $j$ who is in a group $\mathcal{J} = \{1, \ldots, J\}$, and let an argument in square brackets denote time, e.g. $c^j[t]$ is individual $j$'s consumption at time $t$. If $t$ is a decision point for $j$, let $\tau^j[t]$ define the interval to $j$'s next decision and let $\tau^{-j}[t]$ define the interval to the next instance of peer consumption,

$$\tau^{-j}[t] = \min_{j' \in \mathcal{J} \setminus \{j\}} \{z > 0 : c^{j'}[t+z] > 0\}.$$

Then $j$'s realized interval is either the natural interval or the interval to the next instance of peer consumption, whichever comes first:

$$\tau^j = \min \{\bar{\tau}(s^j, c^j), \tau^{-j}\}, \tag{2.13}$$

where the time argument is suppressed. For ease of notation, in results that follow, if there is a common group decision point, all variables missing square brackets implicitly refer to their values at the group decision point.

To study the model absent complicating factors, an idealized, perfect-information setting is constructed. Variation in initial natural decision points and initial habit stocks, $\bar{t}_0^j$ and $s_0^j$, are the only allowable forms of heterogeneity. Membership in a peer group is all-or-nothing and permanent. Now consider a static game in which each $j \in \mathcal{J}$ simultaneously chooses an action, which is a lifetime consumption sequence $\{c_0^j, c_1^j, \ldots\}$. With the initial habit stocks $\{s_0^j\}_{j\in\mathcal{J}}$ and natural decision points $\{\bar{t}_0^j\}_{j\in\mathcal{J}}$ given, the decision points $\{t_0^j, t_1^j, \ldots\}$ — and by extension the payoffs — are determined for each $j \in \mathcal{J}$ from equation (2.13) and the collection $\{c_0^j, c_1^j, \ldots\}_{j\in\mathcal{J}}$ of chosen actions.[37]

### 2.5.2 Facets of Conformity

The group game features a unique Pareto perfect equilibrium (established by Proposition 18 in Appendix 2.7.13). The next three results characterize properties of the equilibrium, each highlighting a distinct channel that promotes the general propensity for group conformity.

**Proposition 14** [Synchronization]: *Under NP, if two members of $\mathcal{J}$ each consume once during a given time-period, then they consume simultaneously.*

[37]The game is modeled as a static choice (in part) for tractability, as the implied dynamic optimization problem mirrors our previous approach. That is, as in the single-agent setting, choosing the lifetime consumption sequence is equivalanet to letting each future $c_i^j$ depend on the habit stock $s_i^j = s^j[t_i^j]$ at the time of the decision. Further, a complication for a dynamic game formulation stems from the fact that whether peers face decisions sequentially or simultaneously is endogenously determined. That is, if a "stage game" occurs at some $t$ when a strict subset of the group $A \subset \mathcal{J}$ naturally faces a decision, then the set of players at $t$ is endogenously determined where members in $\mathcal{J}\backslash A$ "play" at $t$ if and only if $c^j[t] > 0$ for some $j \in A$.

Next, in considering a decision (outside the game) to be in a group, Proposition 15 characterizes an individual's preferences between isolation and the group equilibrium.

**Proposition 15** [Self-Sorting]: *Under NP, suppose individual $j'$ optimally chooses whether to be a member of $\mathcal{J}$ or to be isolated, and everyone has a common initial decision point. If $j'$ chooses to be in $\mathcal{J}$, then* $s^{j'} \geq \max_{j \in \mathcal{J} \setminus \{j'\}} \{s^j\}$.

Lastly, for a homogeneous group, Proposition 16 gives the equilibrium in part (i), and considers a deviation in part (ii).[38]

**Proposition 16** [Herd Behavior]: *Under NP, suppose at a common group decision point $s^j = s^{j'}$ for all $j, j' \in \mathcal{J}$, where $\mathcal{J}$ is exogenously given. Then:*

(i) $c^j = \tilde{c}(s^j)$ *for all $j \in \mathcal{J}$ is the (strategy-unrestricted) outcome.*

(ii) *If some $k \in \mathcal{J}$ deviates from the equilibrium (for an unspecified, idiosyncratic reason) with $\tilde{c}(s^k) \neq c^k > 0$ given, then $c^j = c^k$ for all $j \in \mathcal{J}$.*

To summarize the essence of group behavior from Propositions 14-16: individuals tend to do the same things at the same times because they tend to face the same decisions at the same times (and they prefer to be with those who do). Synchronization arises because whenever someone in the group consumes, everyone simultaneously faces the decision (Proposition 14). Given the option, one will choose to be isolated from a group that contains a higher-habit

[38]The deviation is modeled as a restriction on a player $k$'s action space at a group decision point to a singleton $c^k \in (0, 1]$). Thus part (ii) refers to the unique Pareto perfect equilibrium under this restriction. Propositions 14 and 15 justify aspects of the full homogeneity premise of Proposition 16. Synchronization supports the common initial decision point, and self-sorting lends credence to homogeneous habit stocks.

individual (Proposition 15). As individuals are only mutually willing to be in the same group if each has the (weakly) largest habit stock, any group that forms or continues to exist through endogenous selection must be homogeneous.[39] Avoiding high-habit individuals represents a commitment strategy to prevent frequent peer-induced decisions, which is consistent with self-reports among smokers (Khwaja et al., 2007), and also fits with the smoking stigma and related "social distancing" effect (Stuber et al., 2008). From part (i) of Proposition 16, members of a homogeneous group act as if they were alone (as long as everyone else does too). From part (ii), all others imitate a deviant peer, which preserves the alignment of decision schedules.[40] If the group begins near an unstable steady-state, this herd behavior can impel collective initiation of the habit or collective quitting. The effect is robust to a series of deviations, provided group composition is fixed.

Forces that mitigate the influence of frequent users may prevent heterogeneous habits from coexisting with the rigidity of the group setup. Endogenous selection, as seen, leads to homogeneity. A frequent user who wants to be included in a group with lower-habit individuals may take measures to prevent exclusion. For instance, a new user slightly above the zero-consumption steady-state may apply peer pressure to bring others on board, while a frequent smoker can "leave the room" or refrain from offering cigarettes to others when smoking. If the group isn't always together, the frequent user may space

[39]Even if they are identical, prospective peers may be isolated following endogenous selection because equal-habit individuals are indifferent between being in a group and being isolated. However, a negligible cost to leaving a group (or a negligible benefit to joining) guarantees identical individuals come together.

[40]Imitation is optimal because the usual benefits of both lowering and raising consumption relative to $c^k$ are negated: $c > c^k$ gives $\bar{\tau} > \tau^k$, but it does not lessen short-run opportunity costs because the next decision arrives at $\tau^k$; $c < c^k$ gives $s < s^k$, but it does not reduce the long-run frequency of decisions because future decision points will be a function of $s^k$.

consumption around the times the group congregates.

### 2.5.3 "Coerced" Heterogeneity: Not Following the Leader

Forcing heterogeneous individuals to be in the same group offers a simple premise for a testable prediction:

**Proposition 17** *If $s^{j^+} > s^j$ for all $j \neq j^+ \in \mathcal{J}$ at a common group decision point under NP:*

(i) [High-Habit as Pacesetter]: $\tau^j = \bar{\tau}(s^{j^+}, c^{j^+})$ *for all* $j \in \mathcal{J}$*, with* $c^{j^+} = \tilde{c}(s^{j^+})$.

(ii) [(Feasible) Interval Matching]: *For all* $j \in \mathcal{J} \backslash \{j^+\}$*:* $\bar{\tau}(s^j, 0) \geq \tau^{j^+}$ *if and only if* $c^j = 0$*; and* $\bar{\tau}(s^j, 0) < \tau^{j^+}$ *if and only if* $\bar{\tau}(s^j, c^j) = \tau^{j^+}$.

(iii) [All Others Quit]: $s^j$ *converges to zero for all* $j \in \mathcal{J} \backslash \{j^+\}$

Part (i) implies the most habituated acts as if alone, and is therefore dubbed the "pacesetter" since group decision points are dictated by the highest habit's natural interval. To align decision schedules, part (ii) says others choose consumption to match their natural intervals with the pacesetter's, provided they can. Part (iii) predicts a *negative* peer effect in that all but the pacesetter ultimately quit. Quitting is inevitable because it eventually becomes impossible to keep pace with the pacesetter. To illustrate (iii), suppose the pacesetter is addicted ($s^{j^+} = s^*_H$). Then nonaddicts either choose $c$ to set $\bar{\tau}(s, c) = \tau^*_H$ or consume nothing. Since $\bar{\tau}(s, s) > \tau^*_H$ for $s < s^*_H$ (Assumption 1), consumption must be less than $s$ for any $s > 0$, and consequently $s$ converges to zero.

Coerced heterogeneity would be difficult to test. A group would need to remain together and isolated from others for an extended period of time, while the pacesetter would be barred from withholding offers and from smoking in private. Further, as discussed earlier, behavior may adjust if peers have preferences (apart from decision point considerations) for or against being with each other. To guard against these complications, a two-person group would be ideal. Better yet, a simple automaton — a commonly hypothesized player in dynamic games — could emulate the pacesetter. If the pacesetter is an addict, the automaton would effectively be a metronome, perhaps revealing a cigarette at regular intervals to a subject who smokes less often. In essence, the procedure tests what would happen if discrete-time decision-making is *literally* imposed on an individual, and the negative peer effect reflects the contention that standard time precludes an accurate depiction of the incentives underlying addiction.

As conceived here, the automaton also provides a straightforward means to identify an individual's natural decision points (if isolated from all other cues). Suppose a test subject is instructed to preprogram the times cigarettes are offered where cigarettes are only available through the automaton and cannot be hoarded. Then the chosen times should correspond to the anticipated decision points because access is good conditional on a decision, but bad if it induces a decision.

## 2.6 Conclusions

The *decision* is arguably the single greatest restriction on a choice — when a decision presents itself, an incomprehensible universe of possibilities has already been whittled down to some "manageable set." This paper departs from the common practice that takes decisions as given, proposing a few ideas to explain where decisions for bad habits may come from — cravings, external cues (including the good), peer consumption — why decisions arise when they do, and how choices can influence the timing of future decisions. The framework provides an alternative to standard time's inherent "metronomism," which, as argued, is an overlooked imposition that limits the range and explanatory power of economic models.

From the general notion of a "cue" — exposure to an item or context associated with a behavior — new decision point models can be readily motivated. For instance, *advertisements* can be represented as decision points. Perhaps shedding new light on the tobacco industry's rampant youth-targeting, advertising to a child who has never considered the decision could rouse a new habit (and generate substantial profits), simply by inducing the initial decision point $t_0$.[41] Creating new customers through decision points similarly fits with DiFranza and McAfee's (1992) observation that the tobacco industry "repeats the word 'decision' like a mantra." Even industry "prevention" programs, which consistently draw attention to the *decision* to smoke, appear to be a sly method of propagating decision points among susceptible youth.[42]

[41] Marketers of Camel cigarettes have proven particularly adept at making inroads with the very young, as over 90 percent of six-year olds knew the smoking cartoon "Joe Camel" (Camel's ex-mascot) — a recognition level on par with Mickey Mouse — in a study by Fischer et al. (1991).

[42] The portrayal of smoking as an "adult choice" or "adult decision" is the overarching theme of youth-directed industry programs, according to Landman et al. (2002). The first educational program sponsored by the Tobacco Institute, *Helping Youth Decide*, purports to help "young teenagers learn to make more of their own decisions." Unsurprisingly, Farrelly et al. (2002) find intentions to smoke rise after exposure to a Philip Morris youth anti-smoking campaign.

## 2.7 Appendix

### 2.7.1 Derivation of the Euler Equation

The Euler equation (2.10) is derived from the Bellman equation (2.7), the first-order condition (2.8), and the envelope condition (2.9) as follows: First, substitute out $V'^{+}$ in (2.9) using (2.8). Second, in the new expression for (2.9), iterate every term forward one decision. Again, substitute out $V'^{+}$ (after the iteration) using (2.8). Third, substitute out $V^{++}$ using (2.7) once-iterated — i.e. using the Bellman with the left-side set to $V^{+}$. After solving for $V^{+}$, insert the expression and its once-iterated variant for $V^{++}$ into the left- and right-sides, respectively, of (2.7) to get the Euler equation (2.10). Note, the left-side of the Euler equation is the absolute value of the next-decision value function $-V^{+} > 0$.

### 2.7.2 Discussion of Basic Model Assumptions and Parametric Example

This appendix provides a function $D(s,c) \equiv \delta^{\tau(s,c)}$ and speed factor $\sigma$ that jointly satisfy both assumptions of the basic model (i.e. Assumptions 1 and 2). Hence, the parameterization will accommodate a range of candidate interval functions, as it only specifies $D$, which defines the total discount from the current decision to the next. That is, given any $\delta \in (0,1)$, $\tau(s,c) = \ln(D(s,c))/\ln(\delta)$ defines a suitable interval function (with $\sigma$ and $\delta$). To start, note that the assumptions on $\tau$ given by Assumption 1 can each be expressed as an assumption on $D(s,c)$: (i) $\partial D(s,c)/\partial s > 0$ for all $s, c \in [0,1]$; (ii) $\partial D(s,c)/\partial c < 0$ for all $s, c \in [0,1]$; (iii) $dD(x,x)/dx > 0$ for all

$x \in [0,1]$; (iv) $D(s,c)$ is strictly convex in both arguments. Since $\mu(s,c) = -\frac{\partial}{\partial c}\left(\frac{D(s,c)}{1-D((1-\sigma)s+\sigma c,(1-\sigma)s+\sigma c)}\right)$, the assumptions on $\mu$ can likewise be expressed in terms of $D$. Now consider a cubic for the between-decisions total discount function of the form

$$D(s,c) = \gamma + \gamma_s s + \gamma_c c + \gamma_{ss} s^2 + \gamma_{sc} sc + \gamma_{cc} c^2 + \gamma_{ssc} s^2 c + \gamma_{ssc} sc^2$$

Since $\bar{\mu} = 0$ if and only if $(1-D)D_c + \sigma D(D_s + D_c) = 0$, the speed factor must be

$$\sigma = -\frac{(1-\gamma)\gamma_c}{\gamma(\gamma_s + \gamma_c)}.$$

If we let $\gamma = .85$, $\gamma_s = .09$, $\gamma_c = -.076$, $\gamma_{ss} = .04$, $\gamma_{sc} = -.0372$, $\gamma_{cc} = .001$, $\gamma_{ssc} = -.0003$, and $\gamma_{scc} = -.0009$, we can first verify that $D$ falls within the acceptable range (i.e. on the open unit interval, since $\delta \in (0,1)$ and $\tau > 0$):

$$\min_{s,c} D(s,c) = D(0,1) \quad = .775$$
$$\max_{s,c} D(s,c) = D(1,0) \quad = .98$$

Likewise, $\sigma \approx .884$ also lies in the open unit interval, as it should. Next we can verify the movement function rises from zero:

$$\begin{aligned}\bar{\mu}'(0) &= (1-\gamma)(\gamma_{sc} + 2\gamma_{cc}) - (\gamma_s + \gamma_c)\gamma_c + 2\sigma\gamma(\gamma_{ss} + \gamma_{sc} + \gamma_{cc}) + \sigma(\gamma_s + \gamma_c)^2 \\ &\approx .00216,\end{aligned}$$

and that the movement function is negative at the maximum habit stock:

$$\begin{aligned}\bar{\mu}(1) &= (1 - D(1,1))(\gamma_c + \gamma_{sc} + 2\gamma_{cc} + \gamma_{ssc} + 2\gamma_{scc}) \\ &\quad + \sigma D(1,1)(\gamma_s + \gamma_c + 2(\gamma_{ss} + \gamma_{sc} + \gamma_{cc}) + 3(\gamma_{ssc} + \gamma_{scc})) \approx -.000171\end{aligned}$$

As for the partial derivatives of $D$, it follows from $\gamma_s > |\gamma_{sc} + 2\gamma_{ssc} + \gamma_{scc}|$ that $D_s(s, c) > 0$ for all $s, c$, as desired (i.e. the magnitude of the sum of the only negative terms in $D_s$, $|\gamma_{sc} + 2\gamma_{ssc} + \gamma_{scc}|$, is strictly less than $\gamma_s$, which means the total partial derivative is positive for all $s, c \in [0, 1]$). Likewise, it follows from $|\gamma_c| > 2\gamma_{cc}$ that $D_c(s, c) < 0$ for all $s, c$, as desired (i.e. the only positive term in $D_c$, $2\gamma_{cc}c$, is strictly less than the magnitude of $\gamma_c < 0$, which means their sum is negative for all $s, c \in [0, 1]$). Strict convexity of $D$ in $s$ follows from $\min D_{ss}(s, c) = D_{ss}(s, 1) = .0794 > 0$, and in $c$ follows from $\min D_{ss}(s, c) = D_{ss}(0, c) = .0002 > 0$.

Concavity of $\bar{\mu}$ requires

$$
\begin{aligned}
&[1 - \gamma - (\gamma_s + \gamma_c)s - (\gamma_{ss} + \gamma_{sc} + \gamma_{cc})s^2 - (\gamma_{ssc}+\gamma_{scc})s^3](\gamma_{ssc} + 2\gamma_{scc}) \\
&-[\gamma_s+\gamma_c + 2(\gamma_{ss}+\gamma_{sc}+\gamma_{cc})s + 3(\gamma_{ssc}+\gamma_{scc})s^2][\gamma_{sc}+2\gamma_{cc} + 2(\gamma_{ssc}+2\gamma_{scc})s] \\
&-[(\gamma_{ss}+\gamma_{sc}+\gamma_{cc}) + 3(\gamma_{ssc}+\gamma_{scc})s](\gamma_c + (\gamma_{sc}+2\gamma_{cc})s) \\
&+3\sigma\big\{[\gamma_s+\gamma_c + 2(\gamma_{ss}+\gamma_{sc}+\gamma_{cc})s + 3(\gamma_{ssc}+\gamma_{scc})s^2][(\gamma_{ss}+\gamma_{sc}+\gamma_{cc}) + 3(\gamma_{ssc}+\gamma_{scc})s] \\
&+[\gamma + (\gamma_s+\gamma_c)s + (\gamma_{ss}+\gamma_{sc}+\gamma_{cc})s^2 + (\gamma_{ssc}+\gamma_{scc})s^3](\gamma_{ssc}+\gamma_{scc})\big\} < 0
\end{aligned}
$$

It is verifiable that this is bounded above by $-.002$, as required.

### 2.7.3 Proof of Proposition 7

Proposition 7 parallels a common result in the discrete-time dynamic programming literature, with Stokey, Lucas, and Prescott (1989), hereafter SLP, as our primary reference. We will first show the lifetime utility expression (2.5) has an equivalent (in that the optimal consumption policy is the same) discrete-time, representation with a two-dimensional state-variable in the format of the sequential problem (SP) in SLP, Chapter 4; SP has an equivalent functional equation (FE) representation, from SLP Theorem 4.2. This portion of the proof involves substituting and relabeling variables. The intuition of each step will not be crucial — the key point is that there is nothing in the standard arguments to establish a unique, interior stable steady-state that relies on metronomic time.

To derive equivalent SP and FE discrete-time representations, define $f(s,c) = \delta^{\tau(s,c)-1}$ and $\gamma_i = \delta^{t_i - 1}$. We want to represent $\gamma$ as a state variable. Suppose $\gamma$ evolves by $\gamma_{i+1} = f(s_i, c_i) \cdot \gamma_i$. Under ZP, lifetime utility satisfies:

$$U \;=\; -\sum_{i=0}^{\infty} \delta^{t_i} \;=\; -\sum_{i=0}^{\infty} \delta^i f(s_i, c_i) \cdot \gamma_i \qquad (2.14)$$

As before, given $s_0$, the individual chooses $(c_0, c_1, \ldots)$ to maximize lifetime utility, subject to the habit stock transition equation (2.6). This is the SP — the right-most summation is helpful because its format is compatible with the results of SLP. The corresponding FE is

$$v(x) = \sup_{y \in \Gamma(x)} [F(x,y) + \delta v(y)], \quad \text{all } \; x \in X \qquad (2.15)$$

where: $x = (s_i, \gamma_i)'$, $y = \{(s_{i+1}, \gamma_{i+1})' | c_i\}$, $\Gamma(x) = \{(s_{i+1}, \gamma_{i+1})' : c_i \in [0,1]\}$, and $F(x,y) = f(x^{(1)}, (y^{(1)} - (1-\sigma)x^{(1)})/\sigma) \cdot x^{(2)} = f(s_i, c_i) \cdot \gamma_i$. The parenthetical superscript $(k)$ on $x^{(k)}, y^{(k)}$ denotes the $k$-element, $k = 1, 2$, of the corresponding vector.[43] To satisfy the desired assumptions of SLP, let $\Gamma(x) = \mathbb{R}^2$.

[43]Note that a second state variable, $\gamma_i$, is now needed for the discrete-time equivalent dynamic optimization problem. To see why, first observe that the original Bellman was Markov in that all that matters from the next-decision perspective is $s_{i+1}$, so that $s_{i+1}$ was the only argument in the next-decision future value term. However, the *present* discounted value of the future value term does not depend solely on $s_{i+1}$ because the extent of discounting from the current to the next decision, $\delta^{\tau(s_i, c_i)}$, depends on the current state and choice variables. Thus the second state variable

This generalization is permissible because with unique, interior solutions for optimal consumption on all $s \in [0, 1]$, expanding the domain of the choice variable under concavity does not alter the solution.

Also note the value function is decreasing in the state variable. We can switch the sign on associated monotonicity assumptions and results (which correspond to a value function that is increasing in the state variable), or we can substitute $1 - s$ for $s$ to achieve the same effect. Either correction has the desired effect.

The FE representation for SP is unique, from SLP Theorem 4.3. Thus FE is equivalent to the dynamic optimization problem characterized by the Bellman equation (2.7) in the decision points model. Hence, a result holds for the optimization problem in (2.7) if and only if it holds for the optimization problem in FE. Optimal consumption is single-valued (SLP Theorem 4.8) and the Euler equation (2.10) is sufficient for the optimal consumption sequence (SLP Theorem 4.15). Thus, the steady-state condition, $\bar{\mu}(s) = 0$, derived from the Euler equation is sufficient for an interior steady-state. It follows that $\bar{\mu}(0) = 0$ guarantees $s = 0$ is a steady-state and $\bar{\mu}'(0) > 0$ guarantees its instability. From continuity of $\bar{\mu}$, a unique interior steady-state is guaranteed since $\bar{\mu}(s)$ must equal zero for some $s \in (0, 1)$. ■

### 2.7.4 Proof of Proposition 8

Note NP holds for any result, provided it holds in the limit as $\theta \to 0^+$. Thus if a result holds for ZP, it also holds for NP, unless there is a discontinuity —

$\gamma_i$ is needed for the discrete-time representation to maintain the persistent effect of the current interval on future value terms; accordingly, $\gamma_i$ is (proportional to) the cumulative weight of past discounts.

whether mathematical or in a qualitative property — at $\theta = 0$.

From the NP Bellman, $V(s) = -1 + \max_c \{u(c|\theta) + \delta^{\tau(s,c)} V((1-\sigma)s + \sigma c)\}$, we can derive the first-order and envelope conditions:

$$\begin{aligned} 0 &= u'(c_i|\theta) + \delta^{\tau(s_i,c_i)}[\sigma V'(s_{i+1}) + \ln(\delta)\tau_c(s_i,c_i)V(s_{i+1})], \\ \text{and} \qquad V'(s_i) &= \delta^{\tau(s_i,c_i)}[(1-\sigma)V'(s_{i+1}) + \ln(\delta)\tau_s(s_i,c_i)V(s_{i+1})]. \end{aligned}$$

Setting $c = s$ throughout, we can derive the steady-state condition. Define

$$\bar{\mu}^{\theta}(s) = \bar{\mu}(s) + \frac{u'(s|\theta)[1 - (1-\sigma)\delta^{\tau(s,s)}]}{(1 - \delta^{\tau(s,s)})(1 - u(s|\theta))} < \bar{\mu}(s)$$

Then $\bar{\mu}^{\theta}(s) = 0$ implies $s$ is a steady-state under NP. Its derivative is.

$$\bar{\mu}^{\theta\prime}(s) = \bar{\mu}'(s) + \frac{\sigma(\tau_s + \tau_c)\ln(\delta)\delta^{\tau}u'}{(1 - \delta^{\tau})^2(1 - u)} + \frac{(1 - (1-\sigma)\delta^{\tau})[(u')^2 + (1 - u)u'']}{(1 - \delta^{\tau})(1 - u)^2}$$

where $\tau$ and its partial derivatives are all evaluated at $c = s$. Taking the small $\theta$ limit, all $u$ terms (including derivatives) converge to zero since $u$ is twice continuously differentiable in both arguments.

Therefore $\lim_{\theta\to 0^+} \bar{\mu}^{\theta}(s) = \bar{\mu}(s)$ and $\lim_{\theta\to 0^+} \bar{\mu}^{\theta\prime}(s) = \bar{\mu}'(s)$, i.e. the NP movement function converges to the ZP movement function in the small $\theta$ limit. Since $\bar{\mu}^{\theta\prime}(0) < 0$ for any $\theta > 0$, the marginal returns to consumption from $c = 0$ at zero-habit with $\theta > 0$ is strictly less than the marginal returns with $\theta = 0$. Therefore, optimal consumption is zero at zero-habit, so $s = 0$ remains a steady-state.

By continuous differentiability and convergence of $\bar{\mu}^{\theta}(s)$ to $\bar{\mu}(s)$ with $\bar{\mu}'(0) > 0$ and $\bar{\mu}$ concave: there is a $\theta_1 > 0$ such that $\theta < \theta_1$ implies $\max_s \{\bar{\mu}^{\theta}(s)\} > 0$; and there is a $\theta_2 > 0$ such that $\theta < \theta_2$ implies $\max_s \{\bar{\mu}^{\theta\prime}(0)\} > 0$. With

$\bar{\mu}^{\theta}(s) < \bar{\mu}(s)$, it follows that for sufficiently small $\theta$, $\theta < \min\{\theta_1, \theta_2\}$, there is an interval $[a, b] \subset [0, 1]$ with $0 < a < b < s^*$ such that $\bar{\mu}^{\theta}(s) \geq 0$ iff $s \in [a, b]$, where $\bar{\mu}^{\theta}(s) = 0$ iff $s \in \{a, b\}$. In turn, given small $\theta > 0$, $a$ must be the unstable steady-state since $\bar{\mu}^{\theta'}(a) > 0$ and $b$ the stable steady-state since $\bar{\mu}^{\theta'}(b) < 0$ by convergence to $\bar{\mu}$. ■

### 2.7.5 Proof of Proposition 9

Rearranging the ZP steady-state expression, $\bar{\mu} = 0$, gives:

$$\delta = [1 - \sigma(\tau_s/\tau_c + 1)]^{-1/\tau}, \tag{2.16}$$

where all terms are evaluated at the addicted steady-state. Since $\tau_s + \tau_c < 0$ at a steady-state where $\tau_c > 0$ (Assumption 1), it follows that $\delta \in (0, 1)$ for $\sigma \in (0, 1)$. It also follows that higher $\sigma$ implies lower $\delta$, ceteris paribus, as can be seen from differentiating the right-side of (2.16) with respect to $\sigma$, i.e. $[1 - \sigma(\tau_s/\tau_c + 1)]^{-\frac{1+\tau}{\tau}}\tau^{-1}(\tau_s/\tau_c + 1) < 0$. ■

### 2.7.6 Proof of Corollary 2

MRAS in a steady-state is $(\tau^*)^{-2}[-\sigma\tau^*\tilde{c}'(s^*) + s^*\tau_c^*]$. Observe MRAS is monotonic in $\sigma$ and its limit is positive as $\sigma \to 0$. Consider two cases:

*Case 1.* $\tilde{c}'(s^*) \leq \frac{s^*\tau_c^*}{\tau^*}$. In this case, MRAS is positive for all $\sigma \in (0, 1)$. Then let $\bar{\delta} = \left(\frac{-\tau_c^*}{\tau_s^*}\right)^{1/\tau^*}$, which is the $\delta$ that satisfies the steady-state equation for $\sigma = 1$. It follows that the steady-state exists and adjacent substitution holds for all $\delta \in (\bar{\delta}, 1)$, as desired.

*Case 2.* $\tilde{c}'(s^*) > \frac{s^*\tau_c^*}{\tau^*}$. In this case, the MRAS is negative for $\sigma = 1$. Since

MRAS is linearly decreasing in $\sigma$ and is positive for $\sigma = 0$, there must be a $\sigma \in (0,1)$ such that MRAS is zero. Observe MRAS is zero for $\sigma = \frac{s^*\tau_c^*}{\tau^*\tilde{c}'(s^*)}$. Let the threshold discount factor be that which corresponds to zero MRAS, i.e. $\bar{\delta} = \left(1 - \frac{s^*(\tau_s^*+\tau_c^*)}{\tau^*\tilde{c}'(s^*)}\right)^{-1/\tau^*}$. Then the steady-state exists and adjacent substitution holds for all $\delta \in (\bar{\delta}, 1)$, as desired. ■

### 2.7.7 Proof of Proposition 10

Without loss of generality, suppose $n = i = 0$ and $T_0 = t_0 = 0$. Let $I = \max i : t_i < \ell$, i.e. $t_I$ is the last decision point in the interior of the measured demand period. For notational ease, first consider the ZP case. Then

$$C_1 = \frac{1}{\ell}\int_0^\ell x(i : t_{i-1} < t \leq t_i)dt \quad = \frac{1}{\ell}\left(\sum_{i=1}^{I} c_i\right) + \frac{(\ell - t_I)c_{I+1}}{\ell\tau(s_I, c_I)}.$$

Now measured adjacent substitution (complementarity) holds if the measured MRAS is positive (negative). Since only sign matters, these conditions are equivalent if the measured MRAS is multiplied by the constant $\ell > 0$ (replacing mean with total demand in the numerator). That is, measured adjacent substitution holds if $-\frac{\partial[\ell \cdot C_1]}{\partial c_0} > 0$. For any $\ell < \tau^*$, measured adjacent substitution is satisfied because $-\frac{\partial[\ell \cdot C_1]}{\partial c_0} > 0$ iff $-\frac{\partial[\ell \cdot x(1)\tau^*]}{\partial c_0} > 0$ iff $-\frac{\partial x(1)}{\partial c_0} > 0$, which holds by assumption.

Since $\frac{\partial c_k}{\partial c_0} = \tilde{c}'(s^*)\frac{\partial s_k}{\partial c_0}$ and $\frac{\partial s_1}{\partial c_0} = \sigma$, it follows from the stock transitions that the marginal effect of $c_0$ on future variables is:

$$\begin{aligned}
\frac{\partial s_k}{\partial c_0} &= \sigma[(1-\sigma) + \sigma\tilde{c}'(s^*)]^{k-1} \\
\frac{\partial c_k}{\partial c_0} &= \sigma\tilde{c}'(s^*)[(1-\sigma) + \sigma\tilde{c}'(s^*)]^{k-1}.
\end{aligned}$$

With $\frac{\partial t_1}{\partial c_0} = \tau_c^*$, the effect on future decision points is:

$$\frac{\partial t_{k+1}}{\partial c_0} \;=\; \frac{\partial t_k}{\partial c_0} + \frac{\partial \tau(s_k, c_k)}{\partial c_0} \;=\; \frac{\partial t_k}{\partial c_0} + \tau_s^* \frac{\partial s_k}{\partial c_0} + \tau_c^* \frac{\partial c_k}{\partial c_0}$$

which, for all $k \geq 2$, can alternatively be expressed as

$$\frac{\partial t_k}{\partial c_0} \;=\; \tau_c^* + (\tau_s^* + \tilde{c}'(s^*)\tau_c^*) \frac{1 - [(1-\sigma) + \sigma \tilde{c}'(s^*)]^{k-1}}{1 - \tilde{c}'(s^*)}$$

Now $\bar{\mu}'(s^*) < 0$, which follows from concavity of $\bar{\mu}$ with $\bar{\mu}(0) = 0$ and $\bar{\mu}(1) < 0$. It follows that $\tilde{c}'(s^*) < 1$ since $\tilde{c}(s^* + \epsilon) < s^* + \epsilon$ for $\epsilon > 0$. Further, $s' > s^*$ implies $\mu(s', s^*) > 0$, which implies $\tilde{c}'(s^*) > 0$ since $\tilde{c}(s^* + \epsilon) > s^*$ for $\epsilon > 0$. Therefore, $[(1-\sigma) + \sigma\tilde{c}'(s^*)] \in (0,1)$, so that

$$0 < \frac{\partial s_{k+1}}{\partial c_0} < \frac{\partial s_k}{\partial c_0} \quad \text{and} \quad 0 < \frac{\partial c_{k+1}}{\partial c_0} < \frac{\partial c_k}{\partial c_0} < 0, \quad \text{for all } k \geq 1.$$

Since $\frac{\partial \tau(s_k, c_k)}{\partial c_0} = \sigma(\tau_s^* + \tilde{c}'(s^*)\tau_c^*)[(1-\sigma) + \sigma\tilde{c}'(s^*)]^{k-1}$ with $\tau_s^* + \tilde{c}'(s^*)\tau_c^* < \tau_s^* + \tau_c^* < 0$, we have

$$0 > \frac{\partial \tau(s_{k+1}, c_{k+1})}{\partial c_0} > \frac{\partial \tau(s_k, c_k)}{\partial c_0}, \quad \text{for all } k \geq 1.$$

One implication of this inequality is that $\frac{\partial t_k}{\partial c_0} < 0$ implies $\frac{\partial t_{k+1}}{\partial c_0} < 0$.

**Lemma 2** *There is a $\bar{k} > 1$ such that $\frac{\partial t_{\bar{k}}}{\partial c_0} < 0$.*

**Proof of Lemma 2**

Suppose not. Then $\frac{\partial t_k}{\partial c_0} > 0$ for all $k > 1$. Since lifetime utility under ZP is $U = -\sum \delta^{t_i}$, $\frac{\partial U}{\partial c_0} = -\ln(\delta) \sum \frac{\partial t_i}{\partial c_0} \delta^{t_i} > 0$. Therefore, lifetime utility is increasing in $c_0$, which contradicts the optimality of the steady-state consumption.

Therefore the lemma holds. ■

Now,

$$\frac{\partial[\ell C_1]}{\partial c_0} = \sum_{i=1}^{I} \frac{\partial c_i}{\partial c_0} + \frac{\ell - t_I}{\tau^2}\left(\tau \frac{\partial c_{I+1}}{\partial c_0} - c_{I+1}\frac{\partial \tau(s_I, c_I)}{\partial c_0}\right) - \frac{\partial t_I}{\partial c_0} \cdot \frac{c_{I+1}}{\tau}.$$

If $\frac{\partial t_I}{\partial c_0} < 0$, then every term is positive. Therefore, $-\frac{\partial[\ell C_1]}{\partial c_0} > 0$ for all $\ell > t_{\bar{k}}$ from Lemma 2, so that measured adjacent complementarity holds for sufficiently large $\ell$. Now observe $-\frac{\partial^2[\ell C_1]}{\partial \ell \partial c_0} = -\frac{1}{\tau^2}\left(\tau \frac{\partial c_{I+1}}{\partial c_0} - c_{I+1}\frac{\partial \tau(s_I, c_I)}{\partial c_0}\right)$, which is finite and strictly less than zero for $I > 0$. Hence, since $-\frac{\partial[\ell C_1]}{\partial c_0} > 0$ for small $\ell$, and $-\frac{\partial[\ell C_1]}{\partial c_0} < 0$ for large $\ell$, and $-\frac{\partial[\ell C_1]}{\partial c_0}$ is strictly decreasing in $\ell$, there exists a $\ell^0$ such that $-\frac{\partial[\ell C_1]}{\partial c_0} > 0$ for all $\ell < \ell^0$ and $-\frac{\partial[\ell C_1]}{\partial c_0} < 0$ for all $\ell > \ell^0$. The result extends to NP due to continuity of all terms in the small $\theta$ limit as $s_H^* \to s^*$. ■

### 2.7.8 Proof of Proposition 11

**Proof of Proposition 11, part (i-a)**

Since $C_n$ maximizes $U(C_n|\hat{\delta}_n)$, $U(C_n|\hat{\delta}_n) \geq U(0|\hat{\delta}_n)$. By NP, $U(0|\delta) > U(C_n|\delta)$. Adding the inequalities, substituting $U(C) = U^+(C) + \delta U^-(C)$, and rearranging gives $(\delta - \hat{\delta}_n)(U^-(C_n) - U^-(0)) < 0$. Since $U^-$ is decreasing, $\hat{\delta} < \delta$. ■

**Proof of Proposition 11, part (i-b)**

By the first-order condition that defines $\hat{\delta}_n$, concavity of $U$, and $U(C_n|\hat{\delta}_n) > U(C|\hat{\delta}_n)$ for all $C \neq C_n$, $U(C|\hat{\delta}_n)$ is strictly increasing on $[0, C_n]$. ■

**Proof of Proposition 11, part (ii-a)**

Solving for $\hat{\delta}_{n+1}$ after taking the first-order condition of the utility maximization problem for which it is defined gives

$$\hat{\delta}_{n+1} = -\frac{U^{(+)'}(C_{n+1})}{U^{(-)'}(C_{n+1})} = \frac{U^{(+)'}(C_{n+1})}{|U^{(-)'}(C_{n+1})|}. \tag{2.17}$$

Here, by concavity of both, $U^{(-)'} < 0$ implies $U^{(+)'} > 0$ (otherwise $C_{n+1} > 0$ would not satisfy measured optimality). Since $u$ is strictly concave by NP, $U$ is strictly concave, which means either $U^{+}$ or $U^{-}$ is strictly concave (or both are). Therefore, $\hat{\delta}_{n+1}$ must fall with $C_{n+1}$ since the magnitude of the numerator decreases and the magnitude of the denominator increases (and at most one of these magnitudes are weakly monotonic). Since the measured MRAS, $-\mathrm{E}\left[\frac{\partial C_{n+1}}{\partial C_n}\right]$, is positive for $\ell < \ell^0$ and negative for $\ell > \ell^0$ (proposition 10), increasing chosen consumption at $T(n)$ from the steady-state level decreases $\hat{\delta}_{n+1}$ if $\ell < \ell^0$ and increases $\hat{\delta}_{n+1}$ if $\ell > \ell^0$. ■

**Proof of Proposition 11, part (ii-a)**

Since $\frac{\partial[U'(C|\delta)]}{\partial\delta} = \frac{\partial[U^{(+)'}(C)+\delta U^{(-)'}(C)]}{\partial\delta} = U^{(-)'}(C) < 0$, $U'(C|\hat{\delta}_{n+1})$ moves in the opposite direction as $\hat{\delta}_{n+1}$. Hence, the desired result follows from (ii-a). ■

### 2.7.9 Proof of Lemma 1

Let $\tau^D$ denote any deterministic interval function. We first show there exists a $\tau^D$ such that the optimization problems with $\tau^D$ and with stochastic $\tau$ are equivalent in that optimal $\tilde{c}(s)$ is the same for all $s$. A crucial element of this existence is the fact that the stock transition equation, $s_{i+1} = (1-\sigma)s_i +$

$\sigma c_i$, is retained in the stochastic cues model. Therefore, given $s_i$ and $c_i$, the next-decision habit stock, $s_{i+1}$, is independent of whether the next decision is craving-induced at $\bar{\tau}$ or cue-induced prior to $\bar{\tau}$. Hence the optimization problem at $t_{i+1}$ is also independent of whether the decision is craving- or cue-induced, since $s_{i+1}$ is the only state variable at $t_{i+1}$.

Dynamic optimization with stochastic cues follows:

$$V(s) = -1 + \max_c \{u(c) + \mathrm{E}[\delta^{\tau(s,c)}]V((1-\sigma)s + \sigma c)\}.$$

The next-decision value function is factored out of the expectation because its value depends only on $s$ and $c$. Comparing to the deterministic Bellman

$$V(s) = -1 + \max_c \{u(c) + \delta^{\tau^D(s,c)}V((1-\sigma)s + \sigma c)\},$$

we see the optimization problems are always equivalent if and only if $\delta^{\tau^D} = \mathrm{E}[\delta^\tau]$ for all $s, c$. Therefore, we need to show $\tau^0$ satisfies $\delta^{\tau^0} = \mathrm{E}[\delta^\tau]$. With the known distribution of $\tau$, the expectation of $\delta^\tau$ is computed by decomposing it into its cue- and craving-components:

$$\mathrm{E}[\delta^\tau] = \underbrace{\left[\int_0^{\bar{\tau}} \delta^t \lambda e^{-\lambda t} dt\right]}_{\frac{-\lambda\delta^t e^{-\lambda t}}{\lambda - \ln(\delta)}\Big|_{t=0}^{\bar{\tau}}} + \underbrace{\Pr(\tau = \bar{\tau}) \cdot \delta^{\bar{\tau}}}_{e^{-\lambda\bar{\tau}} \cdot \delta^{\bar{\tau}}} = \frac{-\lambda - e^{-\lambda\bar{\tau}} \ln(\delta)\delta^{\bar{\tau}}}{\lambda - \ln(\delta)}.$$

As desired, $\delta^{\tau^0} = \mathrm{E}[\delta^\tau]$, as seen by the definition $\tau^0 = \frac{\ln[(\lambda - e^{-\lambda\bar{\tau}} \ln(\delta)\delta^{\bar{\tau}})/(\lambda - \ln(\delta))]}{\ln(\delta)}$. ■

### 2.7.10 Proof of Proposition 12

Assimilating our steady-state notation with the notation of this section, we note $\bar{\tau}_L^* > \bar{\tau}_H^*$, which says the chipper's natural interval is greater than the addict's. Since an individual's steady-state consumption level (at each decision) is constant, the share of consumption that coincides with a stochastic cue is $1 - e^{-\lambda\bar{\tau}}$, which is the probability that a decision will be cue-induced. By inspection, we can verify the share is higher for $\bar{\tau} = \bar{\tau}_L^*$ than for $\bar{\tau} = \bar{\tau}_H^*$. Hence, (a) holds.

To prove (b), decompose variance as $\text{Var}[\tau] = \text{E}[\tau^2] - \text{E}[\tau]^2$ and compute:

$$\text{E}[\tau] = \left[\int_0^{\bar{\tau}} t\lambda e^{-\lambda t} dt\right] + e^{-\lambda\bar{\tau}} \cdot \bar{\tau} = \tfrac{1-e^{-\lambda\bar{\tau}}}{\lambda}$$

$$\text{E}[\tau^2] = \left[\int_0^{\bar{\tau}} t^2\lambda e^{-\lambda t} dt\right] + e^{-\lambda\bar{\tau}} \cdot \bar{\tau}^2 = \tfrac{2}{\lambda^2}\big(1 - e^{-\lambda\bar{\tau}}(1 + \lambda\bar{\tau})\big)$$

Therefore $\text{Var}[\tau] = \frac{1-e^{-2\lambda\bar{\tau}}-2\lambda\bar{\tau}e^{-\lambda\bar{\tau}}}{\lambda^2}$. Differentiating with respect to $\bar{\tau}$ gives

$$\frac{\partial \text{Var}[\tau]}{\partial \bar{\tau}} = \frac{2e^{-2\lambda\bar{\tau}}}{\lambda}(e^{-\lambda\bar{\tau}} + \lambda\bar{\tau} - 1),$$

which is positive for all $\bar{\tau} > 0$. Hence variance is higher at $\bar{\tau}_L^*$ than at $\bar{\tau}_H^*$. ■

### 2.7.11 The Dependence of $\text{Var}[\tau^{-1}]$ on Habit Strength

Suppose the cue-arrival probability in a given period is $q \in (0, 1)$, where the true interval is the time from the period of the present decision point until the next cue, unless no cue arrives prior to $\bar{\tau}$ from the present. Then, the interval function is a Poisson random variable, right-censored at $\bar{\tau}$. The variance of the frequency is therefore given by

$$\begin{aligned}\mathrm{Var}[\tau^{-1}|\bar{\tau}] = &\left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t^2}\right] + \frac{(1-q)^{\bar{\tau}}}{\bar{\tau}^2} \\ &- \left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t}\right]^2 - \frac{2(1-q)^{\bar{\tau}}}{\bar{\tau}}\left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t}\right] - \frac{(1-q)^{2\bar{\tau}}}{\bar{\tau}^2}\end{aligned}$$

Define $D(\bar{\tau}) = \mathrm{Var}[\tau^{-1}|\bar{\tau}+1] - \mathrm{Var}[\tau^{-1}|\bar{\tau}]$. To show that the variance of the frequency is increasing in $\bar{\tau}$ (and thus decreasing in $s$), it suffices to show that $D(\bar{\tau}) > 0$ for all $\bar{\tau} = 1, 2, \ldots$. We will proceed by induction. Evaluating the first term gives

$$D(1) = \mathrm{Var}[\tau^{-1}|\bar{\tau}=2] = q\left(\frac{5-q}{4}\right) > 0.$$

Now assume $D(\bar{\tau}-1) > 0$. The value of $D$ evaluated at $\bar{\tau}$ is given by

$$\begin{aligned}D(\bar{\tau}) = &\left[\sum_{t=1}^{\bar{\tau}+1} \frac{q(1-q)^{t-1}}{t^2}\right] + \frac{(1-q)^{\bar{\tau}+1}}{(\bar{\tau}+1)^2} - \left[\sum_{t=1}^{\bar{\tau}+1} \frac{q(1-q)^{t-1}}{t}\right]^2 \\ &- \frac{2(1-q)^{\bar{\tau}+1}}{\bar{\tau}+1}\left[\sum_{t=1}^{\bar{\tau}+1} \frac{q(1-q)^{t-1}}{t}\right] - \frac{(1-q)^{2(\bar{\tau}+1)}}{(\bar{\tau}+1)^2} - \left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t^2}\right] \\ &- \frac{(1-q)^{\bar{\tau}}}{\bar{\tau}^2} + \left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t}\right]^2 + \frac{2(1-q)^{\bar{\tau}}}{\bar{\tau}}\left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t}\right] + \frac{(1-q)^{2\bar{\tau}}}{\bar{\tau}^2} \\ \propto\ &\bar{\tau}^2 - (2q^2+1)(1-q)^{\bar{\tau}}\bar{\tau}^2 + 2\bar{\tau}(\bar{\tau}+1)\left[\sum_{t=1}^{\bar{\tau}} \frac{q(1-q)^{t-1}}{t}\right] - (\bar{\tau}+1)^2 + (1-q)^{\bar{\tau}}(\bar{\tau}+1)^2\end{aligned}$$

Now express $D(\bar{\tau}-1)$ as:

$$
\begin{aligned}
D(\bar{\tau}-1) \propto\ & \frac{\bar{\tau}+1}{\bar{\tau}-1}\Big((\bar{\tau}-1)^2 - (2q^2+1)(1-q)^{\bar{\tau}-1}(\bar{\tau}-1)^2 \\
& \qquad + 2\bar{\tau}(\bar{\tau}-1)\left[\sum_{t=1}^{\bar{\tau}-1}\frac{q(1-q)^{t-1}}{t}\right] - \bar{\tau}^2 + (1-q)^{\bar{\tau}-1}\bar{\tau}^2\Big) \\
=\ & \bar{\tau}^2-1-(2q^2+1)(1-q)^{\bar{\tau}-1}(\bar{\tau}^2-1) \\
& \qquad + 2\bar{\tau}(\bar{\tau}+1)\left[\sum_{t=1}^{\bar{\tau}-1}\frac{q(1-q)^{t-1}}{t}\right] - \frac{\bar{\tau}+1}{\bar{\tau}-1}\bar{\tau}^2 + (1-q)^{\bar{\tau}-1}\frac{\bar{\tau}+1}{\bar{\tau}-1}\bar{\tau}^2.
\end{aligned}
$$

Therefore, for some $\alpha > 0$

$$
\begin{aligned}
D(\bar{\tau})-\alpha D(\bar{\tau}-1) \propto\ & \bar{\tau}^2 - (2q^2+1)(1-q)^{\bar{\tau}}\bar{\tau}^2 + 2\bar{\tau}(\bar{\tau}+1)\left[\sum_{t=1}^{\bar{\tau}}\frac{q(1-q)^{t-1}}{t}\right] - (\bar{\tau}+1)^2 \\
& + (1-q)^{\bar{\tau}}(\bar{\tau}+1)^2 - \bar{\tau}^2 + 1 + (2q^2+1)(1-q)^{\bar{\tau}-1}(\bar{\tau}^2-1) \\
& - 2\bar{\tau}(\bar{\tau}+1)\left[\sum_{t=1}^{\bar{\tau}-1}\frac{q(1-q)^{t-1}}{t}\right] + \frac{\bar{\tau}+1}{\bar{\tau}-1}\bar{\tau}^2 - (1-q)^{\bar{\tau}-1}\frac{\bar{\tau}+1}{\bar{\tau}-1}\bar{\tau}^2.
\end{aligned}
$$

Now this can be reduced to

$$
D(\bar{\tau})-\alpha D(\bar{\tau}-1) \propto\ 1 + q(1-q)^{\bar{\tau}-1}(1+2q^2\bar{\tau}^2+\bar{\tau}^2+2(\bar{\tau}-q)) + \frac{\bar{\tau}^2}{\bar{\tau}-1}(1-(1-q)^{\bar{\tau}-1}) > 0.
$$

Hence $D(\bar{\tau}) > \alpha D(\bar{\tau}-1) > 0$. Therefore, under the discretization, the variance of the frequency is increasing in the natural interval length. Since $\bar{\tau}$ is implicitly a decreasing function of $s^*$, the variance of the frequency for a weaker steady-state habit is higher than the variance of the frequency for a stronger steady-state habit, ceteris paribus. (Put differently, the variance of the consumption frequency is higher for chippers than for addicts). Since this holds for all $q \in (0,1)$ and for any resolution (as the resolution was not specified), it holds in the continuous limit of the discretization.

Now consider an alternate model in which all consumption is triggered by an external cue. Furthermore, suppose the per-decision arrival probability of a stochastic cue is an increasing function of the habit stock. In this case, the variance of the frequency is given by:

$$\text{Var}[\tau^{-1}|\infty] = \left[\sum_{t=1}^{\infty} \frac{q(1-q)^{t-1}}{t^2}\right] - \left[\sum_{t=1}^{\infty} \frac{q(1-q)^{t-1}}{t}\right]^2$$

where $s$ implicitly enters as an argument in each $q$, with $s' > s$ implies $q(s') > q(s)$. Differentiating the above expression with respect to the cue-arrival probability gives:

$$\frac{d\text{Var}[\tau^{-1}|\infty]}{dq} = \left[\sum_{t=1}^{\infty} \frac{d[q(1-q)^{t-1}t^{-2}]}{dq}\right] - 2\left[\sum_{t=1}^{\infty} \frac{q(1-q)^{t-1}}{t}\right]\left[\sum_{t=1}^{\infty} \frac{d[q(1-q)^{t-1}t^{-1}]}{dq}\right]$$
$$\frac{d\text{Var}[\tau^{-1}|\infty]}{dq} \propto Li_2[1-q](1-2q) + q\ln(q) - 2\frac{q\ln(q)^2}{1-q}(1-2q),$$

where $Li_2$ is the dilogarithm:

$$Li_2(z) = \sum_{t=1}^{\infty} \frac{z^t}{t^2}.$$

The variance of the frequency is increasing up to $q \approx .08$. Consider smoking behavior and suppose we set the period length at five minutes, i.e. if we suppose each smoking episode lasts five minutes and treat the period length as the length such that consumption precludes other activities during the period, but does not spill over into other periods. Then the variance of the consumption frequency is increasing in habit strength over the range of habits from abstainers to smokers who spend up to around two hours per day smoking (which translates to 23 smoking episodes per day). Since two dozen cigarettes per day is within the typical range for cigarette addicts, the variance of the frequency is increasing in the habit stock over a realistic range. However, recall that empirical findings indicate consumption patterns become less random and increasingly regimented on the path to addiction. Consequently, this specification, which omits the internal cravings and instead posits that the volume of cues increases in the habit stock, is inadequate. Meanwhile, the prior specification that operated through the dependence of the natural interval function on the habit stock qualitatively matches the evidence. While the variance of $\tau$ — as opposed to the variance of $\tau^{-1}$ — from Proposition 12 sufficed to illustrate the observed regimentation of habits, only the variance of $\tau^{-1}$ comparison distinguishes the model from the "no internal cravings" specification in which the cue-arrival rate rises with habit strength.

### 2.7.12 Proof of Proposition 13

$$\begin{aligned}\mathrm{E}[\delta^{\tau(s,c)}] = {} & \Pr(\tau(s,c) < \bar{\tau}(s,0))\mathrm{E}[\delta^{\tau(s,c)}|\tau(s,c) < \bar{\tau}(s,0)] \\ & + (1 - \Pr(\tau(s,c) < \bar{\tau}(s,0)))\mathrm{E}[\delta^{\tau(s,c)}|\tau(s,c) \geq \bar{\tau}(s,0)]\end{aligned}$$

As $\lambda \to \infty$, $\Pr(\tau(s,c) < \bar{\tau}(s,0)) \to 1$, which implies $\mathrm{E}[\delta^{\tau(s,c)}] \to \mathrm{E}[\delta^{\tau(s,c)}|\tau(s,c) < \bar{\tau}(s,0)]$. This expectation is independent of $c$ since its associated probability distribution is the right-truncated exponential distribution on $(0, \bar{\tau}(s,0))$ for all $c$. Note since $c = 0$ minimizes $\bar{\tau}(s,c)$, this means the probability of a craving-induced decision converges to zero regardless of chosen consumption.

Now inspect the optimization problem given by the Bellman:

$$V(s) = -1 + \max_{c} \{u(c) + \mathrm{E}[\delta^{\tau(s,c)}]V((1-\sigma)s + \sigma c)\}.$$

As $\lambda \to \infty$, $\mathrm{E}[\delta^{\tau(s,c)}] > 0$ converges to a constant and $V((1-\sigma)s + \sigma c)$ falls with $c$. Since $u(c)$ is strictly decreasing for fixed $\theta > 0$, it follows that

$$0 = \lim_{\lambda \to \infty} \left\{ \arg\max_c \left\{ u(c) + \mathrm{E}[\delta^{\tau(s,c)}] V((1-\sigma)s + \sigma c) \right\} \right\},$$

which implies $\lim_{\lambda \to \infty} \tilde{c}(s) = 0$ for all $s$, as desired. ■

### 2.7.13 Group Equilibrium

Let $\mathcal{J}^+ = \{ j \in \mathcal{J} : s_0^j \geq s_0^{j'} \text{ for all } j' \in \mathcal{J} \}$ denote the subset of $\mathcal{J}$ consisting of member(s) who have the highest habit stock in $\mathcal{J}$. Let $\mathcal{J}^\ominus = \mathcal{J} \backslash \mathcal{J}^+$ denote the complement of $\mathcal{J}^+$ with respect to $\mathcal{J}$, i.e. $\mathcal{J}^\ominus$ consists of those who do not have the highest habit stock in $\mathcal{J}$. Denote representative elements as $j^+ \in \mathcal{J}^+$ and $j^\ominus \in \mathcal{J}^\ominus$.

**Proposition 18** [Group Equilibrium]: *Under NP, any Pareto Perfect equilibrium satisfies:*

(i) *For all* $j^+ \in \mathcal{J}^+$, $c_i^{j^+} = \tilde{c}(s_i^{j^+})$, $i = 0, 1, \ldots$.

(ii) *For all* $j^\ominus \in \mathcal{J}^\ominus$*: given* $t^{j^+}$ *is any decision point for any* $j^+ \in \mathcal{J}^+$.

$$\text{Then } c^{j^\ominus}[t_i^{j^+}] = \begin{cases} 0 & \text{if} \quad \bar{\tau}(s^{j^\ominus}[t_i^{j^+}], 0) \geq \bar{\tau}(s_i^{j^+}, c_i^{j^+}) \\ c : \bar{\tau}(s^{j^\ominus}[t_i^{j^+}], c) = \bar{\tau}(s_i^{j^+}, c_i^{j^+}) & \text{if} \quad \bar{\tau}(s^{j^\ominus}[t_i^{j^+}], 0) < \bar{\tau}(s_i^{j^+}, c_i^{j^+}) \end{cases}$$

Note $s^{j^+}$ is fixed for all $j^+ \in \mathcal{J}^+$. Also note the proposition implies $t_i^{j^+}$ is fixed for all $j^+ \in \mathcal{J}^+$ and all $i = 0, 1, \ldots$, unless $s_0^j = 0$ for all $j \in \mathcal{J}$, because for any $s_0 > 0$ there exists a $\bar{\theta} > 0$ such that $\theta < \bar{\theta}$ implies $s_0 > s_L^*$ (which in turn implies $\tilde{c}(s_0) > 0$ and $s_i \to s_H^*$).

**Proof**.

*Case 1:* $s^j = 0$ for all $j \in \mathcal{J}$.

Then $\mathcal{J}^+ = \mathcal{J}$ and $\mathcal{J}^\ominus = \emptyset$, and Proposition 18 asserts $c_i = 0$, $i = 0, 1, \ldots$, for all $j \in \mathcal{J}$. This is a Nash equilibrium because $c_i^j = 0$ maximizes lifetime utility for all $j$, thus there is no incentive to deviate. It is subgame perfect because each subgame is isomorphic to the full game. It is Pareto perfect because it pareto dominates any outcome that involves $c_i^j > 0$ for any $i, j$, and it is the unique Pareto perfect equilibrium for the same reason.

*Case 2:* $s^j > 0$ for at least one $j \in \mathcal{J}$.

To show the strategies for $\mathcal{J}^\ominus$ in (ii) are best responses to strategies for $\mathcal{J}^+$ in (i), note that from $t_0^{j^+}$, each $t_i^{j^+}$ is a decision point for all $j \in \mathcal{J}$.

Therefore, $\max\{\lim_{\theta \to 0^+} U^{j^\ominus}[t_0^{j^+}]\} = -\sum_{i=0}^{\infty} \delta^{t_i^{j^+}}$, where

$$t_{i+1}^{j^+} - t_i^{j^+} = \bar{\tau}(s_i^{j^+}, \tilde{c}(s_i^{j^+})). \tag{2.18}$$

Now (2.18) is violated whenever $\bar{\tau}(s^{j^\ominus}, c^{j^\ominus}) < \bar{\tau}(s^{j^+}, c^{j^+})$. Conditional on (2.18) being satisfied, $U^{j^\ominus}$ is decreasing in $c^{j^\ominus}[t_i^{j^+}]$, ceteris paribus, because $u' < 0$ for $\theta > 0$. Now (ii) satisfies (2.18). Further, (ii) minimizes each $c^{j^\ominus}[t_i^{j^+}]$ subject to satisfying (2.18).[44] Therefore (ii) is a best response to (i).

Since each $j^+ \in \mathcal{J}^+$ can do no better than the outcome conditional on strategies in $\mathcal{J}^+ \backslash \{j^+\}$ and unconditional on strategies in $\mathcal{J}^\ominus$, it too is a best response. Therefore (i) and (ii) form a Nash equilibrium. Since each induced subgame is isomorphic to a full game in which $s^j > 0$ for at least one $j \in \mathcal{J}$, the equilibrium is subgame perfect. Since each $j^+ \in \mathcal{J}^+$ can do no better than the outcome unconditionally, and each $j^\ominus \in \mathcal{J}^\ominus$ can do no better than the outcome conditional on the strategies of each $j^+ \in \mathcal{J}^+$, the equilibrium is

[44] That this holds for all $i = 0, 1, \ldots$ follows recursively because minimizing $c^{j^\ominus}[t_i^{j^\ominus}]$ subject to (2.18) also minimizes the necessary future consumption levels since $\bar{\tau}_s < 0$.

Pareto perfect.

To prove uniqueness of the equilibrium specifications, we will first show that $c^{j^+} = 0$ can never bet a part of a Pareto perfect equilibrium. First note any strategy that involves $c^{j^+} \neq c^{k^+}$, $j^+, k^+ \in \mathcal{J}^+$ cannot be Pareto perfect. This follows because returns are increasing in $c$ from $c = 0$ unless $\lim_{c\to 0} \tau^{-j} < \bar{\tau}(s_i^{j^+}, c)$. However, $s_i^{j^+} = \max_{j\in\mathcal{J}}\{s^j[t_i^{j^+}]\}$, $\min \tau^{-j} > \bar{\tau}(s_i^{j^+}, 0)$ and by continuity of $\bar{\tau}$, $\lim_{c\to 0} \tau^{-j} > \bar{\tau}(s_i^{j^+}, c)$ must hold. Hence any Nash equilibrium must involve $c_i^{j^+} > 0$ unless $\tilde{c}(s_i^{j^+}) = 0$. Therefore, each $j \in \mathcal{J}$ faces a decision at each $t_i^{j^+}$. Thus for any subgame perfect equilibrium, $\lim_{\theta\to 0^+} \max\{U^{j^\ominus}\} = U^{j^+}$. Now $U^{j^+}$ is maximized by the consumption sequence $(\tilde{c}(s_0^{j^+}), \tilde{c}(s_1^{j^+}), \ldots)$, which implies $\lim_{\theta\to 0^+} \max\{U^{j^\ominus}\}$ is likewise maximized by each player $j^+ \in \mathcal{J}^+$ choosing $(\tilde{c}(s_0^{j^+}), \tilde{c}(s_1^{j^+}), \ldots)$. Therefore, any subgame perfect equilibrium that does not involve $(\tilde{c}(s_0^{j^+}), \tilde{c}(s_1^{j^+}), \ldots)$ is Pareto dominated. Thus, since the strategy in part (ii) is the best response to the strategy in part (i), any Pareto perfect equilibrium must satisfy both. ■

### 2.7.14 Proof of Proposition 14

Proposition 14 says: For $j, k \in \mathcal{J}$ and any interval $[\underline{t}, \bar{t}]$. Given: $c^j[t] > 0$, $t \in [\underline{t}, \bar{t}]$ iff $t = t^j$; and $c^k[t] > 0$, $t \in [\underline{t}, \bar{t}]$ iff $t = t^k$. Then $t^j = t^k$.

First note, since $c^j[t^j] > 0$ and $c^j[t^k] > 0$, $t^j$ and $t^k$ are decision points for both $j, k$. We will prove by contradiction, i.e. assume $t^j \neq t^k$.

*Case 1:* $s^j = s^k$. Then $c^j[t] = c^k[t]$ for all $t$ from Proposition 18, so $t^j \neq t^k$ can't hold.

*Case 2: WLOG* $s^j > s^k$ *with* $j \in \mathcal{J}^+$ *(and* $k \in \mathcal{J}^\ominus$*).* Then $s^j[t^k] > s^k[t^k]$ with $\bar{\tau}(s^j[t^k], 0) = \bar{\tau}(s^k[t^k], c^k)$, which cannot hold because $\bar{\tau}_s < 0$ and $\bar{\tau}_c > 0$

from Assumption 1.

*Case 3: WLOG $t^j < t^k$ with $s^j \neq s^k$ and $j, k \in \mathcal{J}^{\ominus}$.* First note, $c^k[t^k] > c^j[t^k]$ and $\bar{\tau}(s^k[t^k], c^k[t^k]) \leq \bar{\tau}(s^j[t^k], 0)$ imply $s^k[t^k] > s^j[t^k]$. Also note $c^j[t^j] > c^k[t^j]$ and $\bar{\tau}(s^j[t^j], c^j[t^j]) \leq \bar{\tau}(s^k[t^j], 0)$ imply $s^j[t^j] > s^k[t^j]$. However, $s^k[t^k] = (1-\sigma)^{n+1} s^k[t^j] < (1-\sigma)^n((1-\sigma)s^j[t^j] + \sigma c^j[t^j]) = s^k[t^k] < s^j[t^k]$, where $n$ is the number of group decision points between (but not including) $t^j$ and $t^k$, which is a contradiction. This exhausts all cases. ∎

### 2.7.15 Proof of Proposition 15

Lifetime utility if $j'$ chooses isolation is $V(s^{j'})$. Given a common group decision point, if $j'$ joins the group, $\lim_{\theta \to 0^+} V^j = V(\max_{j \in \mathcal{J} \cup \{j'\}} \{s^j\})$. Since $V(s^{j'}) \geq V(\max_{j \in \mathcal{J}} \{s^j\})$ and holds with equality iff $s^{j'} = \max_{j \in \mathcal{J} \cup \{j'\}} \{s^j\} \geq \max_{j \in \mathcal{J}} \{s^j\}$, if the individual joins, then $s^{j'} \geq \max_{j \in \mathcal{J}} \{s^j\}$ as desired. ∎

### 2.7.16 Proof of Proposition 16

Part (i) follows directly from part (i) of Proposition 18.

To prove part (ii), first note the outcome with imitation must involve reversion to the single-agent consumption path for subgame perfection. Now given $0 < c^k \neq \tilde{c}(s^k)$, consider the three possibilities:

$c^j = c^k$ implies $V^j[t] = -1 + \delta^{\tau(s^j, c^k)} V((1-\sigma)s^j + c^k)$;

$c^j < c^k$ implies $\max \lim_{\theta \to 0^+} V^j[t] = \max \lim_{\theta \to 0^+} V^k[t] = -1 + \delta^{\tau(s^j, c^j)} V((1-\sigma)s^j + c^k) < -1 + \delta^{\tau(s^j, c^k)} V((1-\sigma)s^j + c^k)$;

$c^j > c^k$ implies $\max \lim_{\theta \to 0^+} V^j[t] = \max \lim_{\theta \to 0^+} V^k[t] = -1 + \delta^{\tau(s^j, c^k)} V((1-\sigma)s^j + c^j) < -1 + \delta^{\tau(s^j, c^k)} V((1-\sigma)s^j + c^k)$;

Therefore the equilibrium with $c^j = c^k$ Pareto dominates any outcome with $c^j \neq c^k$. ■

### 2.7.17 Proof of Proposition 17

Parts (i) and (ii) follow directly from Proposition 18.

For part (iii), note $\lim_{\theta \to 0^+} \{\lim_{i \to \infty} s_i^J = s_H^*\}$ since $s^J > 0$ by heterogeneity of $s^j$.

Now $c^j > 0$ for $j \in \mathcal{J} \backslash \{J\}$ means $\bar{\tau}(s^J, c^J) = \bar{\tau}(s^j, c^j)$, which implies $c^J > c^j$. Thus $s^J[t+\tau^J] = (1-\sigma)s^J[t]+\sigma c^J[t] > (1-\sigma)s^j[t]+\sigma c^j[t] = s^j[t+\tau^J]$.

Therefore $s^j < s^J$ at all group decision points for $j \in \mathcal{J} \backslash \{J\}$.

Now $s^j < s_H^*$ and $\bar{\tau}(s^j, c^j) = \bar{\tau}_H^*$ imply $c^j < s^j$ since $\bar{\tau}(s^j, s^j) < \bar{\tau}_H^*$ from Assumption 1. Therefore, $s_i^j$ is a strictly decreasing sequence for $s^J$ sufficiently close to $s_H^*$. Hence $s_i^j$ converges. If $s_i^j \to s > 0$, then $c_i^j \to s$ and $\bar{\tau}(s_i^j, c_i^j) \to \bar{\tau}(s, s) < \bar{\tau}_H^*$, which contradicts part (ii) of Proposition 18. Therefore $s_i^j \to 0$ for all $j \in \mathcal{J} \backslash \{J\}$. ■

# 3

# The Timing of Decisions in Addiction: A Review of Addiction Research from the Vantage of Endogenous Decision Points

## 3.1 Introduction

The endogenous decision points theory of addiction (Landry, 2012; hereafter EDP) posits that much of the patterns and motivations of addiction can be illuminated through an understanding of the "decision points," i.e. the factors that cause someone to consider the decision to consume an addictive good. First and foremost, the basic model represents internal *cravings* as decision points, as cravings appear to be the most important decision point (and consequently, the main driver of consumption in the state of addiction). Providing realistic enhancements, EDP integrates additional decision point representations into the basic model. Introducing external *cues* as decision points allowed comparisons between weak and strong habits with respect to the predictability or consistency of consumption routines, and also regarding the degree to which demand is linked to cues. With *peer consumption* as a decision point, the group model characterized several aspects of conformity in groups.

This paper reviews addiction research through the lens of the endogenous decision points theory. The review draws on empirical findings from several disciplines, using the language and formalism of economics to interpret the evidence. The evidence will be considered in light of the key formal representations of EDP, as well as the results derived from these decision point representations. Throughout this paper, there will be an emphasis on tobacco addiction because it is the prototype addiction, unrivaled in scale — approximately one billion smokers smoke almost six trillion cigarettes annually, spending nearly a half-trillion dollars on a product that will be responsible for one billion deaths this century (Eriksen et al., 2012). That said, evidence on other substance addictions will be cited to complement the primary findings on tobacco addiction.

Section 3.2 introduces four principal "macroscopic" features of addiction, distilled from the immense addiction literature. These features are macroscopic in the sense that they are not contingent on being able to observe the timing of decisions. Although there are countless, candidate empirical findings on addiction, the four features — the union of which is uniquely captured by the decision points model — are deemed principal because these features are of first-order importance for an economic understanding of addiction (as argued in Section 3.2).

The remainder of the review roughly tracks the progression in EDP. Section 3.3 sketches the construction of the basic cravings model and describes key results. Section 3.4 explores several topics related to the "interval function," which is the formal expression introduced in EDP that indicates the time between consecutive decision points as a function of the choice history. Such topics include: why someone may initiate a bad habit; how someone can quit a bad habit; physiological microfoundations for the interval function (as it relates to cravings); the potential relationship between the decision point representation of a craving and three prominent symptoms of addiction — difficulty sleeping, diminished appetite, and difficulty concentrating during withdrawal; and implications for economic treatments of commitment. Section 3.5 provides background and elaborates on ideas from EDP's inference exercises, in which a hypothesized researcher attempts to ascertain an individual's time and consumption preferences under the false assumption of discrete-time decision-making. The section includes a discussion of the 'liking'-'wanting' gap, noted in neuropsychology research on addiction, and its relationship to the classical habit-formation preferences and rational addiction models in economics.

The final two decision point representations — external cues and peer consumption — are addressed in Sections 3.6-3.7. The cues discussion provides evidence that reinforces key patterns introduced in EDP. Likewise, the discussion of peer effects overviews empirical findings related to the three aspects of conformity captured by EDP that underly the standard "propensity" measure of peer effects: synchronization, self-sorting, and herd-behavior.

## 3.2 Economic Aspects of Addiction: Principal Features

While drawing on empirical regularities from several fields, this section highlights four principal macroscopic features of addiction through an economic lens. The present discussion is restricted to "macroscopic" features of addiction which are independent of the fine structure of time. Because standard economic representations of time preclude endogeneity in the timing of choices, this restriction permits comparisons to existing models and allows us to consider addiction from an empirical perspective, as choices are generally aggregated into metronomic bins in economic data.

### 3.2.1 It's bad.

*Why is addiction an interesting challenge to economics research?*

The tobacco habit, a "mild" drug addiction, is responsible for one in ten human deaths. With use surging in low- and middle-income countries (projected to double from 2000 to 2030), tobacco's share of mortalities is expected to climb (Mathers and Loncar, 2006). While lopping years off the end — Peto et al. (1996) estimate smoking is associated with an eight-year drop in life expectancy — addiction is also a prolific time-killer during life. As Robinson and Berridge (2008) describe, addiction consumes "an inordinate amount of an individual's time and thoughts." This paraphrases official criteria of DSM-IV (Diagnostic and Statistical Manual of Mental Disorders) and ICD-10 (International Classification of Diseases), the respective nomenclatures of the American Psychiatry Association and the World Health Organization (see Hasin et al., 2006). Nearly three-quarters of smokers want to quit and the same fraction try to quit, yet only one in ten attempts is successful (Anda et al., 1987; Hymowitz et al., 1997). Indeed, addiction is "bad" by *definition* in most fields. This tautological view is gaining momentum in economics, manifest in recent addiction theories by Bernheim and Rangel (2004), and Gul and Pesendorfer (2007).[1]

Although "addiction" lacks a working definition, the consensus in economics is that addiction is harmful to the individual. Representative of this view, Akerlof (1991) notes the majority of drug addicts "recognize that the long-run cost of their addiction exceeds its benefits."[2] In the United States, the annual direct medical cost of smoking is over $50 billion; adding indirect morbidity

[1]Bernheim and Rangel advance a clinical conception of addiction, involving consumption "despite clearly harmful consequences." Gul and Pesendorfer consider a health-care conception, as a "disease that impedes the agent's decision-making ability." While agnostic on whether addiction qualifies as a "disease," Gul and Pesendorfer embrace "the problem" of addiction. For unambiguously "bad" definitions of addiction outside of economics, see, for instance, Leshner (1997) or Hyman and Malenka (2001).

[2]While Becker and Murphy's (1988) rational addiction theory may be cast as the notable exception, rational addiction is foremost an achievement in modeling, as its feat was reconciling aspects of addiction with optimization *in spite* of the consensus. The contributions of rational addiction theory are best understood as part of a pioneering research program that greatly expanded the reach of economic analysis — as Becker (1993) explains in his Nobel lecture, the impetus behind rational addiction was "to probe the boundaries of rational choice theory."

and mortality costs, the sum surpasses $100 billion. Researchers speculate this figure is likely dwarfed by harder-to-quantify costs such as coping with premature loss of a loved one or the pain associated with smoking-related illnesses (Chaloupka and Warner, 2000; Hopkins et al., 2001). Econometric evidence is presented by Kan (2007) who finds support for bans and tax increases among smokers who want to quit, and by Gruber and Mullainathan (2005), who find those prone to smoke are happier following hikes on cigarette excise taxes.

### 3.2.2 Addicts exhibit forward-looking, optimizing behavior.

*How has economics researched challenged our understanding of addiction?*

While early addiction theories relied on a myopic neglect of future harmful consequences, empirical studies reveal addicts behave in a forward-looking manner, validating a central tenet of Becker and Murphy's (1988) rational addiction theory. Several analyses demonstrate cigarette demand falls with future price increases (see, for instance: Chaloupka, 1991; Becker et al., 1994; Gruber and Koszegi, 2001). Forward-looking behavior persists across age groups, according to studies of the young (Gruber and Zinman, 2001) and the elderly (Arcidiacono et al., 2007). Jofre-Bonet and Petry (2008) show forward-looking behavior holds for addictions to harder drugs such as cocaine and heroin. Behavioral economic research supports the econometric evidence, as consumption decreases with a proxy for price in a laboratory setting (Bickel et al., 1998).

As forward-looking behavior also involves being adequately informed of future risks, survey data indicate ignorance of tobacco's health risks is not a significant factor in sustaining addiction (Khwaja et al., 2009). Related research diminishes the role of ignorance. Fenn et al. (2001) find that smokers recognized and accounted for long-term health risks even before the release of the 1979 Surgeon General's report, the first public information campaign to detail the hazards of smoking. In fact, smokers tend to *overestimate* the risk of lung cancer, according to survey data from Viscusi (1990). However, the findings are not unanimous (e.g. Schoenbaum, 1997; Hammond et al., 2006) and important, systematic information asymmetries exist in the cigarette market. For instance, the tobacco industry designs "light" cigarettes to trick the FTC smoking machines into registering lower nicotine and tar yields than yields realized by human smokers (Pollay and Dewhirst, 2002). Consequently, a large majority of smokers falsely believe light cigarettes deliver less nicotine and tar than regular cigarettes (Kozlowski et al., 1998; Shiffman et al., 2001).

### 3.2.3 Opportunity costs are the main driver of addiction.

*What type of "payoff" incentivizes addictive behavior?*

If we start from the premise that there is a strategic incentive for addictive behavior, it can be deduced that addictive behavior is largely incentivized by the desire to manage and minimize opportunity costs. To start, the bulk of addiction research indicates it is not pleasure, but the "withdrawal cost" that drives addiction (Piasecki et al., 1997; Kenny and Markou, 2001; Koob and Le Moal, 2001). The deemphasis on pleasure fits with the neuroscience consensus that "hedonic effects" are not critical to understanding addiction, as noted by Caplin and Dean (2008) and covered in depth by Bernheim and Rangel (2004). (Also see Koob and Le Moal, 2001; Robinson and Berridge, 2001; and Hyman et al., 2006). Further, the subjective enjoyment of drug use does not increase with the onset of addiction and use often becomes disassociated from its subjective effects (Robinson and Berridge, 2000).

How are opportunity costs inherent in withdrawal? Physical withdrawal symptoms "may be largely irrelevant" as a motive for consumption, according to Koob and Le Moal (2001), since recovering addicts relapse "long after physical signs of withdrawal have dissipated." This suggests it is not a direct cost that motivates relapse. Further, poor concentration is a prominent withdrawal symptom (Bell et al., 1999; Cox et al., 2006); poor concentration constitutes an opportunity cost because it detracts from attention allocated to other activities. As Baker et al. (2004) describe, drug use "fills the world with other potential reinforcers." Lastly, as indirect evidence of the role of opportunity costs, addictive choices are highly dependent on concurrent activities and opportunities (Bickel et al., 1995; Bickel et al., 1998).

### 3.2.4 Adjacent Substitution (with Distant Complementarity)

*What demand patterns characterize addiction?*

Drug-seeking, in which an addict continually craves the good until it is consumed, is a common behavior exemplifying *adjacent substitution.*, which means that demand in the short-run future falls with present consumption. Equating cravings to demand, adjacent substitution follows from the fact that drug use alleviates cravings in the short-run. Representative of a large literature, Bell et al. (1999) observe smoking "decreases tobacco craving" for nicotine-deprived addicts, while Koob and Le Moal (2008) conversely note cigarette addicts experience "intense cravings during abstinence." Bickel et al. (1998) show price increases trigger drug-seeking, as addicts substitute to future (and presumably cheaper) consumption. Further, Rose et al. (1984) find smokers prefer higher nicotine intake following two hours of cigarette deprivation. Substitution persists to longer time-scales too. Daily consumption falls by less than the share of time during the workday when a workplace smoking ban is instituted (Evans et al., 1999), implying smokers substitute towards consumption outside working hours. When smokers must limit daily consumption to five cigarettes (from an average of about forty), nicotine intake per cigarette triples (Benowitz, 1988). Erskine et al. (2010) illustrate how substitution holds at least one week into the future, as smoking increases after a week of attempted abstinence, relative to a control group.

*Distant complementarity*, which means demand in a sufficiently "distant" future rises with present consumption, arises because drug use reinforces long-term dependence. Inferred from economic analyses, complementarity overtakes substitution one year after consumption at the latest (Chaloupka, 1991; Becker et al., 1994).

## 3.3 Cravings Model

To provide a foundation to contextualize the review, this section sketches the basic model construction from EDP. The key assumptions, which are (mostly) based on properties of cravings, are also introduced. After presenting the key equations that characterize the basic model's dynamic optimization problems (one each for the two specifications of consumption preferences considered in EDP), the main results are briefly summarized and related back to the principal features from Section 3.2.

To simplify the payoff structure while highlighting the novel and crucial features of the model, each decision point $(t_0, t_1, \ldots)$, i.e. the times the agent considers the consumption decision, involves a -1 decision opportunity cost. This decision opportunity cost reflects the notion that when a craving strikes, it disrupts "normal life," detracting from outside opportunities. It follows that in the basic construction (in which the decision opportunity cost is the only payoff parameter), lifetime utility is simply

$$-\sum_{i=0}^{\infty} \delta^{t_i},$$

where $\delta \in (0, 1)$ is a constant discount factor. The decision points are endogenously determined as a function of past choices (and past decision points). To capture this formally in a parsimonious way, at a decision point $t_i$, $c_i \in [0, 1]$ denotes chosen consumption and $s_i \in [0, 1]$ denotes the *habit stock*. The habit stock is a proxy for prior consumption that transitions according to $s_{i+1} = (1-\sigma)s_i + \sigma c_i$, where $\sigma \in (0, 1)$. The *interval function* $\tau$ determines the time from one decision to the next:

$$\tau(s_i, c_i) = t_{i+1} - t_i.$$

The key assumptions on $\tau$ are:

(i) $\tau_s < 0$

(ii) $\tau_c > 0$

(iii) $s' > s$ implies $\tau(s', s') < \tau(s, s)$

(iv) $-\delta^{\tau}$ is concave

Part (i) captures the common understanding that cravings are more frequent for more habituated individuals, ceteris paribus. Part (ii) captures the fact that cravings tend to subside in the short-run as present consumption increases. Part (iii) strengthens part (i), in a sense, for individuals at a candidate steady-state with $c = s$, as it reflects the fact that even though highly habituated individuals likely consume more when they consider the decision than less habituated individuals, the highly habituated still have more frequent cravings. Part (iv) is primarily a technical assumption, but also embeds an interpretation that the "returns" to consumption — i.e. the capacity to dampen the next-decision opportunity cost via discounting — are diminishing.

Dynamic optimization is characterized by

$$V(s) = -1 + \max_c \{\delta^{\tau(s,c)} V[(1-\sigma)s + \sigma c]\}. \tag{3.19}$$

With additional curvature and calibration assumptions (see BH), the basic model generates a stable steady-state of addiction. Behavior in the addicted steady-state is described by the level and the frequency of consumption.

Because there are no direct returns to consumption, equation (3.19) corresponds to the "zero static consumption preferences" (ZP) specification. Under "negative static consumption preferences" (NP), a nonpositive, decreasing utility function is incorporated, so dynamic optimization under NP is given by

$$V(s) = -1 + \max_c \{u(c) + \delta^{\tau(s,c)} V[(1-\sigma)s + \sigma c]\}.$$

With NP, there are three steady-states: (i) a stable, zero-consumption steady-state at $s = 0$; (ii) an unstable, "chipper" steady-state at $s_L^*$; and (iii) a stable, addicted steady-state at $s_H^*$, where $s_H^* > s_L^* > 0$. As direct costs increase (i.e. replacing $u$ with some $\bar{u}$ with $\bar{u}(c) < u(c)$ and $\bar{u}'(c) < u'(c)$ for all $c > 0$), the zero-consumption steady-state becomes more stable (larger margin for error), as the prominence of chippers rises relative to addicts. Addicts have a higher level and a higher frequency of consumption than chippers.

For either preference specification, the characterization of addiction satisfies four principal features of addiction introduced in Section 3.2, namely: (i) it is bad; (ii) it is consistent with forward-looking optimization; (iii) opportunity costs drive addictive consumption; and (iv) substitution over short-horizons ("adjacent substitution") with complementarity over long-horizons ("distant complementarity").

## 3.4 A Closer Look at the Interval Function

Based on characteristics of the interval function, $\tau$, the next two subsections motivate transitions between equilibria — for initiating the habit and for quitting. The discussion on quitting also relates to the physiological microfoundations for $\tau$. The remaining subsections of this section explore other concepts that tie in to properties of $\tau$ (as it pertains to cravings).

### 3.4.1 Quitting by "Upgrading" Interval Functions (and Microfoundations)

> "I smoked cigarettes for about nine years ... I quit smoking by dipping snuff. I quit that by chewing long-leaf tobacco. Eventually I got down to cigars."

George W. Bush, *Decision Points*, page 1

Taking up an alternative tobacco habit is the most "successful" quitting method, as ranked by the likelihood of giving up cigarettes (Fiore et al., 1990; Rodu and Phillips, 2008). Its viability stems from the notion that low blood nicotine levels give rise to cravings (Jarvik et al., 2000). Crudely suppose a craving arises when blood nicotine drops below a threshold (that depends on $s$). Then $\tau$ defines the interval from a craving to the time nicotine again falls below the threshold.

Other tobacco products appear to have superior interval functions (i.e. larger values of $\tau$ for the same $s, c$) because the "timetable for withdrawal" due to low blood nicotine is particularly unfavorable for cigarettes: nicotine from inhaled cigarette smoke enters the bloodstream faster (and consequently leaves sooner) than from the alternatives (Benowitz et al., 1988). This capacity to ebb cravings is reminiscent of nicotine replacement therapies such as the nicotine patch, which qualitatively has the same advantages as smokeless tobacco products regarding blood absorption rates (Henningfield, 1995). Since these products involve less frequent decision points (a prerequisite for the "opportunity" to consume), the patch and other nicotine sources are valuable commitment devices.

The notion that, due to their "better" (i.e. slower) nicotine absorption rates, different tobacco products can reduce the frequency of decisions relative to cigarettes touches on the physiological microfoundations of $\tau$. Product-specific nicotine absorption rates, and hence product-specific interval functions, can be largely traced to "biological geometry." The rapid absorption from cigarettes is attributed to the large surface area of alveoli in the lungs

(Hukkanen et al., 2005); meanwhile, the gradual buildup from chewing tobacco and oral snuff is traced, respectively, to the slow passage through the buccal (cheek) route and through the mucous membrane (Russell et al., 1976; Fant et al., 1999). Relative to other modeling devices (utility functions, discount factors, information sets, etc.), $\tau$ may be the most "tangible," having the clearest map to its biological roots.

### 3.4.2 Initiation: Peer Pressure and the Low-Habit Shape of $\tau$

A common reason for starting smoking is "peer pressure," in which an individual is urged by a peer to try (Evans et al., 1978; de Vries et al., 2003). Since choosing to abstain may invite insistent requests to consume, peer pressure can justify why, despite the negligible role of cravings, $\tau$ increases with consumption at zero habit.[3] Hence, the interval function introduced in the basic model may represent a reduced form of sorts in that it accounts for some sources of decision points other than internal cravings. This observation highlights the versatility of the decision point construct, as it alludes to EDP's later formalization of peer consumption as a decision point. The notion that peer pressure can implicitly be present in $\tau$ is not double counting when peer consumption is formally motivated. Since peer pressure is only informally motivated in the peer consumption model, the formal treatment is compatible with and complementary to this depiction of peer pressure. (Provided group composition is not permanently fixed, in EDP, an individual who

[3]In the initial construction, the curvature of $\tau$ is insufficient to motivate initial use from $s = 0$ (an implication of zero "movement" from $s = 0$ under ZP). However, this was just an anchoring assumption to generate a zero-consumption equilibrium. Realistically, if peer pressure is sufficiently intense, $\tau_c(0, 0) > 0$ may be large enough to bump the movement function above zero (since larger $\tau_c$ means greater returns to consumption), putting the peer-pressured individual on the path to long-term addiction under ZP. For NP, there is a buffer such that the individual may return to the zero-consumption steady-state after peer pressure subsides.

values group inclusion and is slightly above a zero habit stock would have an incentive to apply peer pressure to zero-habit peers to bring them on board with the new habit. Otherwise, the individual faces the possibility of eventual exclusion from the group.) Further, lumping peer pressure with cravings is mechanically not too much of stretch — and in fact illustrates an important parallel — because within the mechanics of endogenous decision points, peer pressure and cravings function in a similar manner; that is, both peer pressure and cravings penalize the individual who abstains by escalating the arrival of unwanted decision points in the short-run, thereby motivating consumption.

### 3.4.3 Other Symptoms

The notion that decision points interrupt outside opportunities may embed explanations for aspects of the addiction syndrome that seem beyond the reach of economic formalism. With the depiction of cravings as distractions, it would be expected that difficulty concentrating is a defining withdrawal symptom (as addressed in Section 3.2.3). The related supposition that cravings alert the decisionmaking apparatus also suggests a reason why smokers have more trouble falling and staying asleep than nonsmokers (Phillips and Danner, 1995), and why disturbed sleep with frequent wakings is a symptom of nicotine withdrawal (Benowitz, 1988; Shiffman et al., 1995).

Noting the outside opportunity couches all other behaviors, if frequent tobacco cravings compete for “attention” with food cravings and with the eating activity itself, perhaps decision points can help explain why many smoke as a weight loss strategy (Klesges and Klesges, 1988), and why being a smoker is associated with reduced appetite and food intake (Klesges et al., 1989; Jo et al., 2002). A common conclusion is that quitting leads to weight gain and initiation to weight loss (e.g. Flegal et al., 1995; Chou et al., 2004), although Courtemanche (2009) provides a recent negative result. While other mechanisms are certainly involved — e.g. nicotine's impact on metabolic processes (Audrain-McGovern and Benowitz, 2011) — "competing decision points" could very well be a contributing factor, as heavy smokers report that they experience a heightened craving state every thirty minutes and are in a state of craving roughly half the time they aren't smoking (Shiffman and Paty, 2006).

### 3.4.4 Decision-Level Commitment

The model embeds a novel characterization of commitment: with its capacity to postpone the next decision, *consumption* is a commitment device.[4] Moreover, since a decision point is a limitation on outside opportunities, "commitment" and "flexibility" are two sides of the same coin, which contrasts familiar notions in which commitment and flexibility are opposites, defined by constricted and expanded choice sets, respectively. When commitment with respect to a particular decision is valuable, the proper inference is the associated decision brings less utility than the outside opportunity. This decision-level treatment seems appropriate for hard-to-resit urges since a neglected urge is an ongoing drain on decisionmaking faculties.

Thus commitment is a strategy to ward off a persistent distraction, thereby avoiding the opportunity costs of a compromised capacity to engage or ponder

[4]It seems bizarre — the purported purpose of commitment is to *prevent* consumption in the face of temptation — yet consumption functions in the same manner as classical time-inconsistent representations. Laibson's (1997) canonical "golden eggs" hyperbolic discounting model conceptualizes an illiquid asset as a commitment mechanism. Illiquidity requires an individual to wait an extra period to spend proceeds after selling off the asset. As with smoking a cigarette, illiquidity's value in the golden eggs model is owed to its capacity to delay the next opportunity to consume.

alternate activities. This characterization fits behavior patterns and psychology concepts. In the paper commonly cited as the psychological basis for hyperbolic discounting, Ainslie (1975) writes, referring to a nasty urge, "the constant opportunity to do this is a 'distraction,' a tax on the attention paid to more rewarding activities." Meanwhile, keeping busy (e.g. reading, cleaning, physical activity) is a popular strategy to distract oneself from smoking urges (Shiffman, 1984; Khwaja et al., 2007). Decision-level commitment also fits with Ainslie's (1986) description of attentional control as a crucial commitment method. Still, the notion that succumbing is itself a strategy to get a nagging urge of one's mind is a novel characterization of commitment through endogenous decision points.

### 3.4.5 Measured versus Interval-Driven Substitution

The substitution threshold $\ell^0$ may serve as a crude measure for the duration of withdrawal because once withdrawal ends, so does the barrage of cravings that makes abstinence unappealing. Addictive substances are characterized by relatively long durations of withdrawal — three to four weeks for nicotine and up to ten weeks for cocaine (Hughes et al., 1994). This jibes with the incentivizing force inherent in interval-driven adjacent substitution because if withdrawal is too short-lived, it is not worthwhile to consume.

Becker (1992) provides the strongest acknowledgment of adjacent substitution in the habit-formation literature: "if I just ate a filling dinner, I do not want to eat another dinner in the near future ... essentially all goods are substitutes if the time intervals are sufficiently close and the quantities consumed are big enough." While predominantly considered in the realm of eating, Becker's observation reflects the essence of the substitution threshold result — that sufficiently small intervals will "measure" adjacent substitution.

In existing microeconomic treatments, adjacent substitution connotes *satiation* of a desire, marked by a taste for marginal consumption that falls with past use (e.g. Iannaccone, 1986; Dockner and Feichtinger, 1993). While adjacent substitution is not pivotal for the incentive to eat (even if starvation did not bring intense hunger, I would still have a motive to eat), if endogenous arrival of hunger (i.e. food cravings) causes the individual to consider eating, then endogenous decision points and interval-driven adjacent substitution are valid for eating habits too. Moreover, measured adjacent substitution masks the strategic motive to consume since it does not detect the endogenous intervals or the decision opportunity costs. This a noteworthy omission in light of the fact that considerable theoretical interest in addiction is largely due to the difficulty of justifying *why* a rational agent would use drugs.

## 3.5 Apparent versus True Preferences

If the motivation for addictive behavior is based on endogenous intervals, how can a harmful addiction be rationalized in a standard-time world? To investigate, EDP develops a simple procedure that ignores the timing of decisions to "measure" preferences. The misspecified model is estimated using time-aggregated choices from endogenous decision points. As the key determinants of behavior in the standard time setup, the procedure infers static consumption preferences and time preference, i.e. discounting. The next subsection gives relevant background on discounting.

### 3.5.1 Time-Preference: Background and Anomalies

Constant discounting, which posits an invariant subjective discount factor $\delta$, is the standard approach to evaluate intertemporal tradeoffs (Samuelson, 1937; Koopmans, 1960). However, constant discounting faces many empirical challenges and addiction research, in particular, is fertile grounds for apparent departures.

Indicative of *commodity dependence*, several studies find addicts discount drugs more steeply than money: Bickel et al. (1999) find smokers discount cigarettes more than money. Similar studies show heroin addicts discount heroin more than money (Madden et al., 1997; Kirby et al., 1999). There is evidence of commodity dependence even within the health domain: Khwaja et al. (2007) report smokers are as patient as nonsmokers regarding their willingness to undergo a colonoscopy. The notion that discounting ought to be the same for all types of consumption is a universal feature of standard discounting and popular alternatives. The theoretical justification for commodity independence is put best by Frederick et al. (2002): "If people discount utility from different sources at different rates, then the notion of a unitary time preference is meaningless. Instead we would need to label time preference according to the object being delayed — 'banana time preference,' 'vacation time preference,' and so on."

Related estimates based on cigarette demand suggest absurd levels of impatience: for instance, implied subjective discount rates from Becker et al. (1994) range from 56 to 223 percent. Analogous estimates from Baltagi and Griffin (2001) are 32 to 84 percent, though the authors describe several difficulties in measurement. Note, constant discounting can equivalently be expressed as a unitary discount rate $\rho$ (where $\delta = \frac{1}{1+\rho}$), which is considered "reasonable" if it is in the ballpark of a market rate of return on investments. That the subjective discount rate equals the mean (real) interest rate is common in macroeconomics, either as a result or as an assumption. Otherwise, money is left on the table in a standard representative agent economy, since capital markets would provide arbitrage opportunities.

Another noted anomaly is *endogenous discounting*, as estimated patience increases with recent drug use, while the reverse relationship emerges over long horizons. The short-term effect is documented for smokers by (Field et al., 2006) and for heroin addicts by (Giordano et al., 2002). Conversely, ex-users are substantially more patient than current users for cigarettes (Bickel et al., 1999), and for heroin and amphetamines (Bretteville-Jensen, 1999). While noting the possibility that selection may account for the divergence between current and ex-users, Bretteville-Jensen writes: "great impatience and short-sightedness will probably also arise as a result of addiction." Bickel et al. likewise conclude: "never- and ex-smokers could discount similarly because cigarette smoking is associated with a reversible increases in discounting or due to selection bias." The long-horizon form is captured by earlier endogenous discounting theories in which drug use leads to steeper impatience (Becker and Mulligan, 1997; Orphanides and Zervos, 1998).

### 3.5.2 The Liking-Wanting Gap

As mentioned in EDP, the characterization of habit formation preferences as an artifact of misspecification has neuropsychological backing, as drugs are 'wanted' more-and-more despite not being 'liked' more-and-more as addiction develops (Robinson and Berridge, 1993). In economic parlance, 'liking' naturally maps to the true consumption preference and 'wanting' to demand. In common psychology usage, 'liking' refers to the pleasure from drug use, and 'wanting' to the desire to use drugs — Berridge and Robinson (1998) offer definitions based on underlying core processes, in which 'liking' refers to hedonic evaluation and 'wanting' refers to carrying out the drug use routine that culminates with consumption.[5]

While preferences and emergent behavior patterns in the decision point model may reconcile their divergence, there are multiple ways to translate the wanting-liking gap into an economic model. Based on Kahneman et al.'s (1997) decoupling of utility into separate forms, Camerer (2006) equates 'liking' to "experienced utility" and 'wanting' to "decision utility," suggesting they may diverge in addiction (among other contexts). This approach was partially alluded to by Berridge and Robinson (1998) and endorsed by Berridge (2009). However, the difference in interpretations is not trivial, as behavioral representations based on separate utility types do not challenge the metronomism that renders omitted variable bias (that is, the decision is still taken as given).

## 3.6 External Cues

The relative importance of stochastic cues is compared for a chipper and an addict:

1. (i) the proportion of consumption that coincides with a stochastic cue is smaller for the addict.

[5] Neuroscience researchers appear to have identified the "dopaminergic" (relating to the neurotransmitter dopamine) processes responsible for the liking-wanting gap. See Bernheim and Rangel (2004) for an overview of related evidence.

2. (ii) the consumption patterns are less random (i.e. the variance of the interval between consumption occasions is smaller) for the addict.

### 3.6.1 Comparing the Effect of Cues for Addicts and Chippers

As BH addresses, the role of cues differs between weak habits and strong habits; namely, the consumption patterns of chippers are far more dependent on cues than the consumption patterns of addicts (Shiffman et al., 2004; Shiffman and Paty, 2006; Shiffman and Sayette, 2005). This diminishing influence of cues (with rising nicotine dependence) is corroborated by several studies not cited in the original paper. An early experiment by Herman (1974) finds prominently displaying cigarettes has a greater effect on the smoking behavior of chippers than addicts. Responding to a survey by Shiffman et al. (1994), chippers attribute their motivation to smoke more to social factors than to "inner need," while addicts say the opposite. Based on speeds of visual orienting to smoking-related versus smoking-unrelated stimuli, Hogarth et al. (2003) observe smoking cues are substantially more salient for chippers than for addicts. Based on subjective cravings data, Watson et al. (2010) report cue reactivity is significantly and negatively correlated with nicotine dependence.

### 3.6.2 Support for the Decision Point Representation

The influence of a single cue is reminiscent of an internal craving: when a cue arises, the urge to consume suddenly materializes. In fact, cues induce cravings and likewise reorient decisionmaking faculties towards the craved good — as Berridge and Aldridge (2008) write, cues appear to "momentarily dominate decision-making" — lending credence to the formalization of cues as decision points in EDP The cues-cravings link is covered by Grant et al. (1996), Sayette et al. (2001), and Carpenter et al. (2009). For relevant background on cue-induced cognitive reorientation, see Sayette and Hufford (1994), Franken et al. (2005), and Cox et al. (2006).

### 3.6.3 The Good as a Cue

The good as a persistent cue fits with the common attribution of cues' motivational force to the fact that they tend to signal availability of the good.[6] As mentioned in BH, Waters et al. (2004) find that while the nicotine patch reduces the baseline urge to smoke, it does not reduce the spike in the urge from handling a cigarette. This finding corroborated an earlier study by Tiffany et al. (2000). Shiffman et al. (2003) demonstrate the same effects for nicotine gum.[7] For general evidence that drug cues promote relapse, see Niaura et al. (1988) and Shiffman et al. (1996).

## 3.7 Peer Effects

To explore group behavior, in BH, Section 5, peer consumption is modeled as a decision point. The representation captures three aspects of conformity:

1. (i) *Synchronization*: if any two members of a group each consume once in a given time-period, then they consume simultaneously.

2. (ii) *Self-Sorting*: if two individuals are mutually willing to form a group,

[6] The role of availability in cues is covered by Droungas et al. (1995), Juliano and Brandon (1998), and Carter and Tiffany (2001).

[7] Refer to Section 3.4.1 for an interpretation of nicotine replacement therapies in terms of endogenous decision points.

they are equally habituated; if they are not equally habituated, the lower-habit individual strictly prefers isolation to group-formation.

3. (iii) *Herd Behavior*: Within a homogeneous group, members behave identicallyas it is even rational to imitate a deviant peer who strays from the optimal equilibrium.

Each aspect helps give rise to a general notion that the prevalence or level of drug use among one's peers increases the individual's own propensity to use drugs. This general notion is the standard propensity measure of peer effects in economics, which is confirmed by several studies (e.g. Gaviria and Raphael, 2001; Powell et al., 2005; Nakajima, 2007; Fletcher, 2010). Such peer effects appear to be an important driver of bad habits in the early stages of addiction. Ellickson et al. (2003) estimate approximately one-quarter of the association between past and future smoking is attributable to peer effects in a longitudinal sample of middle school students.

Assimilating findings from multiple disciplines, a clearer picture emerges of the patterns underlying the economic propensity measure of peer effects, as ample direct evidence supports each of the three aspects of conformity from peer-induced decision points.

### 3.7.1 Synchronization

Synchronization is best illustrated by the prominence of "social smokers," which is a type of chipper (occasional user) who predominantly smokes in unison with others. Social smokers comprise approximately one-quarter of all smokers and one-half of college smokers (Schane et al., 2009; Moran et al., 2004).

### 3.7.2 Self-Sorting

Several studies documenting general adolescent peer effects report a proclivity to sort into relatively homogeneous groups (Engels et al., 1997; Kobus, 2003; Stewart-Knox et al., 2005). Ennett and Bauman (1994) estimate selection is approximately as important as within-group influences for conformity in groups. Not only based on present habit strengths, self-sorting also occurs with respect to future intentions. Support groups are an important example of peer selection where addicts seeking to quit can congregate (Battaglini et al., 2005).

The mechanism driving self-sorting in decision point theory, namely that low-habit individuals avoid high-habit individuals, is consistent with evidence that nonsmokers primarily deselect from smokers (Ennett and Bauman, 1994). Deselection from more frequent users also fits with the emergence of smoking as a stigmatized behavior (Kim and Shanahan, 2003; Stuber et al., 2008), and motivates the observed "social distancing" effect, in which nonsmokers or light smokers seek to reduce social interactions with heavy smokers. The motive to avoid frequent users is also consistent with expressed smoking-related attitudes. Stuber et al. (2008) take a closer look at the perception of stigma using survey data. More than half of those surveyed agree that most nonsmokers are reluctant to date a smoker, or to let a smoker care for their children, but a majority disagrees with the notion that most nonsmokers think less of smokers, or that smoking is a sign of personal failure. The breakdown suggests the stigma perception arises primarily because people don't want to be in the vicinity of smokers, as opposed to how nonsmokers personally feel about those who smoke. This assessment is compatible with the result because it illustrates strategic value in minimizing social interactions with frequent smokers (while low types wouldn't mind if users smoke in private). Further, avoiding smokers as a commitment device is consistent with self-reports (Khwaja et al., 2007).

### 3.7.3 Herd Behavior

Demonstrating *herd behavior*: individuals tend to conform to the predominant behavior in their peer group, including the collective adoption of new behaviors — most notably when hopping on (or falling off) the smoking bandwagon in tandem with peers. Several of the cited studies for self-sorting also find herd-like behavior within adolescent peer groups. Herds have a pronounced role in the initiation of bad habits, but can also move in the difficult direction: Christakis and Fowler (2008) report whole groups frequently quit smoking in concert, and the cessation of a peer increases a smoker's odds of quitting by a quarter or more.[8]

Addiction research can also help motivate and aid out understanding of the decision point representation driving the results. Peer consumption follows from the general definition of a cue, as it provides exposure to an item (the good) and a context (consumption itself) associated with consumption. The idea of peer consumption as a cue is often put into practice in experimental research, as smoking in the presence of test subjects is a commonly-used laboratory cue to elicit cravings. As with a "cue," the peer consumption representation encapsulates multiple submodels. Peer-induced decisions can likely

[8]For related evidence and discussion, also see Mermelstein et al. (1986), Havassy et al. (1991), and Jones (1994).

arise through "mere proximity" and through communication, presumably direct offers — a common rule in smoking etiquette where before lighting up, a smoker asks peers if they too would like a cigarette. Proximity and offers are each independently associated with a propensity to smoke (Ellickson et al., 2003). Direct offers, meanwhile, are the number one social factor associated with smoking (Conrad et al., 1992).

### 3.7.4 *Negative* Peer Effects?

The prediction may not be as bizarre as it sounds in light of reported asymmetric effects from having smokers in a peer group, as peer smoking promotes initiation for new users but does not deter quits for existing users (Maxwell, 2002; Ennett and Bauman, 1994). Christakis and Fowler (2008) document polarization within a large group with interconnected subgroups, in which entire subgroups quit while smokers drift to the periphery (which also fits with the motive to avoid frequent users).

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# Biography

Peter Reed Landry was born on November 11, 1983 in Midland, Michigan to Janis Ellen Landry-Lane and Timothy David Landry. A graduate of Herbert Henry Dow High School, Peter earned a BS in Physics from the University of Michigan in 2006. For graduate school, Peter attended Duke University where he received his MA and his PhD in Economics, in 2010 and 2013, respectively.