PROJECTION BIAS IN PREDICTING FUTURE UTILITY*

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People exaggerate the degree to which their future tastes will resemble their current tastes. We present evidence from a variety of domains which demonstrates the prevalence of such *projection bias,* develop a formal model of it, and use this model to demonstrate its importance in economic environments. We show that, when people exhibit habit formation, projection bias leads people to consume too much early in life, and to decide, as time passes, to consume more—and save less—than originally planned. Projection bias can also lead to misguided purchases of durable goods. We discuss a number of additional applications and implications.

> The great source of both the misery and disorders of human life, seems to arise from over-rating the difference between one permanent situation and another. Avarice over-rates the difference between poverty and riches: ambition, that between a private and a public station: vain-glory, that between obscurity and extensive reputation—Adam Smith, *The Theory of Moral Sentiments* [2002, p. 173; III,iii,31].

I. Introduction

Optimal decision-making often requires a prediction of future tastes, and future tastes may differ from current tastes due to such factors as habit formation, day-to-day mood fluctuations, social influences, maturation, and changes in the environment.

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When making summer vacation plans during the cold of winter, people must predict what vacations will be most enjoyable during the heat of summer. When ordering food at the beginning of a meal, people must predict how hungry they will be at the end of the meal. When contemplating smoking cigarettes or indulging in other habit-forming substances, people must predict how this consumption will affect their future desire for and enjoyment of these substances.

In this paper we provide evidence for, formalize, and explore the implications of a general bias in the prediction of future tastes: people tend to understand qualitatively the directions in which their tastes will change, but systematically underestimate the magnitudes of these changes. Hence, they tend to exaggerate the degree to which their future tastes will resemble their current tastes. Such *projection bias* may cause people making summer vacation plans in the winter to choose overly warm destinations, diners to order too much food at the beginning of meals, and people unaddicted to cigarettes to underestimate the power of and drawbacks of addiction.

In Section II we review evidence from a variety of domains supporting the existence of projection bias. People underappreciate the effects of long-term changes in tastes, such as those that result from adaptation to a shifting standard of living. People also underappreciate the effects of frequently fluctuating tastes, such as fluctuating hunger. Indeed, virtually all evidence we are familiar with on misprediction of future tastes is consistent with projection bias.

In Section III we develop a formal model of projection bias. To fix ideas, suppose that a person's instantaneous utility can be written as $u(c,s)$, where c is her consumption and s is a "state" that parameterizes her tastes. Suppose further that the person with current state s' must predict her tastes at a time in the future when her state will be s. Consistent with evidence that people tend to understand the qualitative nature of changes in tastes, but underestimate the degree of change, we assume that the person's prediction of her own future preferences, $\tilde{u}(c,s|s')$, lies somewhere "in between" her true future tastes $u(c,s)$ and her current tastes $u(c,s')$. Our formal analysis in this paper assumes that $\tilde{u}(c,s|s')$ is a simple linear combination of $u(c,s)$ and $u(c,s')$, which we refer to as *simple projection bias.*

Because projection bias leads to discrepancies between predicted and subsequently realized utilities, it implies that a person's behavior need not correspond to correct intertemporal utility maximization. For instance, if current consumption has deleterious effects on future well-being, and projection bias leads the person to underappreciate these effects, she may overconsume relative to what would maximize her true intertemporal utility. Moreover, as tastes change over time in ways she does not predict, a person makes plans that she may end up not carrying out; that is, projection bias can lead to dynamic inconsistency. A stressed undergraduate who underappreciates the addictiveness of cigarettes, for instance, might start smoking with the plan of quitting upon graduation, only to continue smoking after graduation once she becomes addicted.

To demonstrate the potential economic importance of projection bias, in Sections IV and V we formally analyze two economic environments. Section IV explores the implications of projection bias in a life-cycle consumption model with habit formation. When consumption is habit-forming, a person should rationally pursue an increasing consumption profile, so that she is always consuming more than she is accustomed to. Projection bias leads a person to underappreciate the impact of current consumption on future utility, and hence to consume too much early in life and too little late in life relative to what would be optimal. More interesting, as time passes and the person habituates to higher consumption levels, she may decide to consume more than she had earlier planned; hence projection bias can cause saving to fall short of intentions. Finally, as the person gets accustomed to higher consumption levels, she also values income more highly, and hence might decide to work more (or retire later) than she had earlier planned.

In Section V we show how projection bias can cause misguided purchases of durable goods. The satisfaction that a person derives from a durable good often fluctuates from day to day, and projection bias leads a person to underappreciate how much her future valuations may differ from her current valuation. As a result, people will overvalue the good on high-value days and undervalue it on low-value days. A person making a one-time buying decision is therefore equally likely to buy when she should not or not to buy when she should. However, if the person has multiple opportunities to buy, and (as is typically the case) unbuying is more difficult than buying, projection bias will lead on average to overpurchasing of durable goods.

We believe that projection bias is important for many economic applications, and that it can provide an intuitive and parsimonious account for many phenomena that are otherwise difficult to explain. In Section VI we extrapolate from our formal analysis in Sections IV and V and discuss some of these additional implications. We conclude in Section VII.

II. Evidence of Projection Bias

In this section we review evidence from a variety of domains supporting the existence of projection bias.[1] A common type of taste change is adaptation: people have a remarkable ability to adapt to major changes in their life circumstances, such as acquiring serious medical conditions, moving to different climates, and changing occupations (see Helson [1964] and Frederick and Loewenstein [1999] for a recent review).[2] Moreover, there is a great deal of evidence that people underappreciate the extent of such adaptation. Specifically, by comparing a "control" group's predictions for how some major change would affect their lives to the self-reports of people who have actually experienced that change, a number of studies suggest that people overestimate the impact of major changes on their long-run level of happiness.

In the medical domain, cross-sectional studies have consistently found that nonpatients' predictions of the quality of life associated with serious medical conditions are lower than actual patients' self-reported quality of life. For instance, Sackett and Torrance [1978] find that nonpatients predict that chronic dialysis would yield a quality of life of 0.39, whereas dialysis patients report a quality of life of 0.56 (on a 0 to 1 scale on which 0 means as bad as death and 1 means perfect health). Boyd et al. [1990] find analogous cross-sectional results with regard to colostomies. The same pattern also shows up in longitudinal studies. Jepson, Loewenstein, and Ubel [2001] asked people waiting for a kidney transplant to predict what their quality of life would be one year later if they did or did not receive a transplant, and then asked

1. See Loewenstein and Schkade [1999] for a summary of much of the evidence presented in this section, as well as for a discussion of the psychological mechanisms that underlie projection bias. Also see Loewenstein, O'Donoghue, and Rabin [2002] for a more extensive discussion of this evidence.

2. There are some exceptions to this rule. First, there are a variety of factors that impede adaptation, such as uncertainty about whether a situation is permanent and repeated reminders of the original situation. Second, some studies have found that people do not seem to adapt to noise; indeed, if anything, they seem to become increasingly irritated by it (for an overview, see Weinstein [1982]). Moreover, noise is the one example we know of that might contradict our assertion that people understand the direction in which tastes change, because people seem to predict that they will adapt when in fact they tend to become more irritated.

those same people one year later to report their quality of life. Patients who received transplants predicted a higher quality of life than they ended up reporting, and those who did not predicted a lower quality of life than they ended up reporting. Sieff, Dawes, and Loewenstein [1999] find similar longitudinal results for people testing for HIV.

Outside the medical domain, Gilbert et al. [1998] compared (among other things) assistant professors' predictions of the impact of getting or being denied tenure to the self-reports of former assistant professors, and Loewenstein and Frederick [1997] compared the predictions by survey respondents of how various events (e.g., a decline in sport fishing and an increase in the number of coffee shops) would affect their well-being over the next decade to the self-reports of other respondents about how actual events in the past decade had affected their well-being. A clear pattern emerged in both studies: those making prospective predictions expected future changes to affect their well-being more than those making retrospective evaluations reported that matched changes in the past had affected their well-being.

While there are alternative explanations for the results above, other research suggests that they are driven in large part by underappreciation of adaptation. First, in the medical domain, recent research by Ubel, Loewenstein, and Jepson [2003] shows that it is sometimes possible to "debias" people—to bring nonpatients' predictions closer to patients' self-reports—by inducing them to think more carefully about adaptation, which suggests that underappreciation of adaptation plays a significant role in the discrepancy. Second, a number of ongoing studies are ruling out other explanations. For instance, a commonly mentioned alternative is "response norming"—chronic dialysis patients, for instance, might interpret a 0.8 on a 0-to-1 scale differently from nonpatients—but Baron et al. [forthcoming] found that making the scales more precise only increases the discrepancy.[3] Finally, and perhaps more importantly, analogous results are found in experiments on shorter term changes in tastes, for which these alternative explanations do not hold; we turn to such evidence next.

3. The other main explanation that has been offered is a "focusing illusion"—that people exaggerate the impact of anything their attention is focused on, including disabilities [Schkade and Kahneman 1998; Wilson et al. 2000]. However, Ubel, Loewenstein, and Jepson [2003] also found that a wide range of "defocusing" interventions actually decreased rather than increased nonpatients' estimates of patients' quality of life.

A prevalent experimental finding is the *endowment effect:* people tend to value an object (such as a coffee mug) more highly if they possess it than if they do not.[4] The usual explanation is that people adapt to owning or not owning the object, and that there is more pain upon parting with the object than there is joy upon obtaining the object. An underappreciation of this adaptation implies that unendowed subjects should underestimate by how much becoming endowed will increase their valuation, and that endowed subjects should underestimate by how much becoming unendowed will decrease their valuation. Van Boven, Dunning, and Loewenstein [2000] find cross-sectional evidence of both predictions. In one experiment the usual endowment effect was replicated by eliciting selling prices from subjects endowed with coffee mugs and buying prices from subjects not endowed (average selling price = $6.37; average buying price = $1.85). Sellers were then asked to estimate how much buyers would pay, and buyers were asked to estimate how much sellers would charge, with subjects rewarded for accurate predictions. Consistent with projection bias, the average estimate of sellers ($3.93) was less than their own average selling price but more than the average buying price, and the average estimate of buyers ($4.39) was more than their own average buying price but less than the average selling price. Loewenstein and Adler [1995] provide longitudinal evidence of the former prediction. In one study, subjects were shown a coffee mug, told to imagine that they had been given one but had the opportunity to exchange it for cash, and then filled out a form that elicited their predicted reservation values. After a delay, they were actually given the mug, and then asked to complete an identical form that elicited their actual reservation values. Again consistent with projection bias, the predicted selling prices were significantly lower than the actual selling prices.

There is also considerable evidence on underappreciation of the effects of hunger. This evidence is particularly valuable because it demonstrates that the same basic pattern of misprediction—understanding the direction of taste changes but underappreciating the magnitude of the changes—shows up for other types of taste changes besides adaptation, and it can show up

4. The endowment effect was first discussed by Thaler [1980]; see Kahneman, Knetsch, and Thaler [1991] for a review.

TABLE I
PERCENTAGE OF SUBJECTS CHOOSING UNHEALTHY SNACK
(FROM READ AND VAN LEEUWEN [1998])

		Future hunger	
		Hungry	Satiated
Current	Hungry	78%	42%
Hunger	Satiated	56%	26%

even for taste changes with which people have ample experience and hence ought to understand well.

Several studies lend support to the folk wisdom that shopping on an empty stomach leads people to buy too much [Nisbett and Kanouse 1968; Gilbert, Gill, and Wilson 2002]. This phenomenon can be interpreted as a manifestation of projection bias: people who are hungry act as if their future taste for food will reflect such hunger. Read and van Leeuwen [1998] provide even sharper evidence of projection bias with respect to hunger. Office workers were asked to choose between healthy snacks and unhealthy snacks that they would receive in one week, either at a time when they should expect to be hungry (late in the afternoon) or satiated (immediately after lunch).[5] Subjects were approached to make the choice either when they were hungry (late in the afternoon) or satiated (immediately after lunch). As depicted in Table I, people who expected to be hungry the next week were more likely to opt for unhealthy snacks, presumably reflecting an increased taste for unhealthy snacks in the hungry state, but in addition, people who were hungry *when they made the choice* were more likely to opt for unhealthy snacks, suggesting that people were projecting their current tastes onto their future tastes.

Indeed, if we interpret the main diagonal—the hungry-hungry and satiated-satiated conditions—as reflecting true preferences, the data fit exactly the pattern of projection bias. For those subjects who are currently hungry but expect to be satiated, they understand the direction in which their tastes will change as they become satiated—fewer choose the unhealthy snack than in the hungry-hungry condition—but they underestimate the magni-

5. The healthy snacks were apples and bananas; the unhealthy snacks were crisps, borrelnoten, Mars Bars, and Snickers Bars. We adopt the terminology healthy and unhealthy from the experimenters, but none of the snacks were thusly labeled to the subjects.

tude of this change—more choose the unhealthy snack than in the satiated-satiated condition. An analogous conclusion holds for subjects who are currently satiated and expect to be hungry.

While we have limited our detailed discussion to a few realms, there is considerable further evidence that projection bias operates across a broad array of domains. Indeed, virtually all evidence that we are aware of is consistent with projection bias (except possibly noise, as discussed in footnote 2).[6] Our goal in the remainder of this paper is to demonstrate its potential importance for economics.

III. The Model

In this section we build a formal model of projection bias. To describe changes in tastes, we use the apparatus of state-dependent utility. Suppose that a person's instantaneous utility in period τ, which captures her tastes, is given by $u(c_\tau, s_\tau)$, where c_τ is her period τ consumption. The variable s_τ, her "state," parameterizes her tastes. The state might reflect past behavior, as when past consumption of a good determines current addiction to that good, or exogenous factors, as when fluctuations in serotonin levels affect mood or when peer pressure affects the benefits and costs of current behavior.[7]

Next consider a person currently with state s' who is attempting to predict her future instantaneous utility from consuming c in state s; that is, she is trying to predict $u(c,s)$. Let $\tilde{u}(c,s|s')$ denote her prediction. If she were accurate, her predicted utility would equal true utility, or $\tilde{u}(c,s|s') = u(c,s)$. But the evidence in Section II suggests that, while people understand the qualitative

6. Other domains for which there is evidence consistent with projection bias include sexual arousal [Loewenstein, Nagin, and Paternoster 1997], pain [Read and Loewenstein 1999], thirst [Van Boven and Loewenstein 2003], fear [Van Boven et al. 2003], and heroin craving [Giordano et al. 2001]. See also Loewenstein's [1996, 1999] discussion of hot/cold empathy gaps wherein individuals who are in cold visceral states underappreciate the impact of hot visceral states on their own behavior.

7. By "consumption," we mean any current physical experience that is relevant for current well-being—in addition to literal consumption of goods, this might include experiencing a health outcome, being exposed to noise, or owning an object. Just as the utility from consuming goods might change over time, the utility from these other types of experiences might change over time, and we capture such effects with the "state" variable. For instance, the utility (quality of life) from being a chronic-dialysis patient might depend on how accustomed the person is to being a chronic-dialysis patient; in this case, consumption is being a chronic-dialysis patient, and the state reflects how accustomed the person is to being a chronic-dialysis patient.

nature of changes in their tastes, they underestimate the magnitude of these changes. Roughly speaking, this *projection bias* means that a person's predicted utility $\tilde{u}(c,s|s')$ lies "in between" her true future utility $u(c,s)$ and her utility given her current state $u(c,s')$.[8] In this paper we consider a particularly simple form of projection bias.

DEFINITION 1. Predicted utility exhibits *simple projection bias* if there exists $\alpha \in [0,1]$ such that for all c, s, and s', $\tilde{u}(c,s|s') = (1 - \alpha)u(c,s) + \alpha u(c,s')$.

With this formulation, if $\alpha = 0$, the person has no projection bias: she predicts her future instantaneous utility correctly. If $\alpha > 0$, the person has projection bias; the bigger is α, the stronger is the bias. When $\alpha = 1$, the person perceives that her future tastes will be identical to her current tastes.[9]

Our model says nothing about how tastes change; rather, it makes predictions as a function of how tastes change. Hence, it might be that a person's happiness tends to mean-revert over time due to adaptation, in which case projection bias would lead her to expect some but not enough mean reversion. It could be that a person develops a taste for certain types of consumption—e.g., her enjoyment of coffee might grow over time—in which case projection bias would lead her to underappreciate how much her enjoyment will grow. Or it could be that a person's tastes fluctuate from day to day, in which case projection bias would lead her to underappreciate the magnitudes of these fluctuations. Our formulation permits us to analyze the implications of projection bias—of understanding the direction of taste changes but under-

8. Our formal assumption is that people correctly anticipate changes in states but underappreciate how these changes map into changes in utility. But since states are merely a means of parameterizing utility functions, it would make little difference if we assumed instead that people fully appreciate how changes in states map into changes in utility but underappreciate the degree to which the states will change.

9. While simple projection bias is sufficient for our analysis in this paper, it is too restrictive for use as a general definition. One problem is that, when there are multiple states, it requires that the magnitude of the bias be identical for different types of states; e.g., that a person who is currently not thirsty and currently unaddicted to cocaine be just as bad at predicting her preferences when she is thirsty as she is at predicting her preferences when addicted to cocaine. A second problem is that the magnitude of the bias cannot depend on the current state; e.g., it does not permit that a satiated person can predict well her preferences when hungry whereas a hungry person cannot predict well her preferences when satiated. See Appendix A in Loewenstein, O'Donoghue, and Rabin [2002] for a more general formulation of projection bias.

estimating magnitudes—for these and other possible types of taste changes.[10]

Most economic decisions involve more than merely predicting future tastes; they involve making choices with intertemporal consequences. We next embed our framework above within an intertemporal-choice environment. Suppose that a person must choose a path of consumption $(c_t, \ldots, c_T)$ when her (true) intertemporal preferences are given by

$$U^t(c_t, \ldots, c_T) = \sum_{\tau=t}^{T} \delta^{\tau} u(c_{\tau}, s_{\tau}),$$

where $\delta \leq 1$ is her discount factor. Standard economic models of state-dependent preferences typically assume that people are "rational" in the sense that they correctly anticipate how their behavior influences the evolution of states. Formally, for any period t and initial state s_t, a rational person chooses a path of consumption $(c_t, \ldots, c_T)$, correctly anticipating the associated path of states $(s_t, \ldots, s_T)$, to maximize true intertemporal utility U^t.

A person with projection bias *attempts* to maximize her intertemporal utility, but may fail to do so because she mispredicts her future instantaneous utilities. More precisely, if a person exhibits projection bias and her state in period t is s_t, then she perceives her period t intertemporal preferences to be

$$\tilde{U}^t(c_t, \ldots, c_T | s_t) = \sum_{\tau=t}^{T} \delta^{\tau} \tilde{u}(c_{\tau}, s_{\tau} | s_t).$$

We assume that for any period t and initial state s_t a person with projection bias chooses a path of consumption $(c_t, \ldots, c_T)$, correctly anticipating the associated path of states $(s_t, \ldots, s_T)$, to maximize her perceived intertemporal utility $\tilde{U}^t$. That is, she behaves exactly as a rational person would except that (possibly) $\tilde{U}^t \neq U^t$.

To incorporate uncertainty over future consumption or future states, we make the standard assumption that a person maximizes her expected discounted utility. For instance, suppose that in period t the person expects her period τ consumption-state combination to be (c', s') with probability p and (c'', s'') with prob-

10. For a discussion of many different types of taste changes, see Loewenstein and Angner [2003].

ability $1 - p$. Just as true period τ expected utility is $E_t[u(c_\tau,s_\tau)] = pu(c',s') + (1-p)u(c'',s'')$, a person with projection bias predicts period τ expected utility to be $E_t[\tilde{u}(c_\tau,s_\tau|s_t)] = p\tilde{u}(c',s'|s_t) + (1-p)\tilde{u}(c'',s''|s_t)$. Similarly, true expected intertemporal utility is $E_t[U^t(c_t, \ldots, c_T)] = E_t[\Sigma_{\tau=t}^{T} \delta^\tau u(c_\tau,s_\tau)]$, and a person with projection bias perceives her expected intertemporal utility to be $E_t[\tilde{U}^t(c_t, \ldots, c_T|s_t)] = E_t[\Sigma_{\tau=t}^{T} \delta^\tau \tilde{u}(c_\tau,s_\tau|s_t)]$.[11]

While the person's true intertemporal preferences U^t are time-consistent, because she incorrectly predicts how her tastes change over time, her perceived intertemporal preferences $\tilde{U}^t$ can be time-inconsistent. Because this time inconsistency derives solely from misprediction of future utilities, it would make little sense to assume that the person is fully aware of it.[12] We assume throughout the paper that the person is completely unaware of the time inconsistency—that at all times the person perceives her preferences to be time-consistent, and therefore at all times she plans to follow the consumption path that maximizes her current perceived intertemporal preferences. As a result, projection bias can lead to *dynamic inconsistency*: a person may plan to behave a certain way in the future, but later, in the absence of new information, revise this plan.[13]

Given any particular set of state-dependent preferences and particular economic environment, our model of projection bias makes specific predictions about how actual behavior differs from rational behavior. To demonstrate this point, and to highlight the

11. Research has, of course, documented a number of inadequacies of expected-utility theory (for an overview see Starmer [2000]). To the extent that one feels the need to modify expected-utility theory for rational types, one could use the same modifications for people with projection bias.

12. Another psychological phenomenon that has received increasing attention in research on intertemporal choice is hyperbolic discounting (see in particular, Laibson [1994, 1997] and O'Donoghue and Rabin [1999a]). Under hyperbolic discounting, true preferences are time-inconsistent, and hence a person could be fully aware of this fact, as much of the literature has assumed.

13. Given the logic of our model, it is inherent that a person is unaware of her *current* misprediction. But one could imagine a variant of the model where the person is aware of her *future* propensity to mispredict. She could, for instance, be aware of her general propensity to overshop when hungry, while still committing the error on a case-by-case basis. The coexistence of day-to-day mispredictions with a "meta-awareness" of these mispredictions is similar to the discussion in O'Donoghue and Rabin [1999b] of how people can simultaneously be aware of their general tendency to procrastinate and yet still procrastinate on a case-by-case basis. A model of "sophisticated projection bias" could plausibly better describe behavior in some circumstances, such as when sophisticated shoppers know that they should not shop on an empty stomach, but we choose our current formulation as a simple and realistic starting point.

potential importance of projection bias for economics, Sections IV and V formally analyze two economic environments.

IV. Projection Bias and Habit Formation

For half a century, though most intensively recently, economists have explored life-cycle consumption models with habit formation. Habit formation—wherein increases in current consumption increase future marginal utility—was discussed by Duesenberry [1949], and later formalized by Pollak [1970] and Ryder and Heal [1973]. In recent years, habit-formation models have been used in specific applications: see Becker and Murphy [1988], Constantinides [1990], Abel [1990], Campbell and Cochrane [1999], Jermann [1998], Boldrin, Christiano, and Fisher [2001], Carroll, Overland, and Weil [2000], and Fuhrer [2000]. All of these recent researchers have examined habit formation within the rational-choice framework.[14]

In this section we formally analyze the implications of projection bias over habit formation in a simple "eat-the-cake" model. Suppose that a person has income Y to allocate over consumption in periods $1, \ldots, T$, which we denote by $c_1, \ldots, c_T$. For simplicity, we assume that there is no discounting, and that the person can borrow and save at 0 percent interest; neither of these assumptions is important for our qualitative conclusions. The person's true instantaneous utility in period t is $u(c_t,s_t)$, where the state s_t can be thought of as her "habit stock." The person's initial habit stock, s_1 is exogenous, and her habit stock evolves according to $s_t = (1 - \gamma)s_{t-1} + \gamma c_{t-1}$ for some $\gamma \in (0,1]$. Hence, the more the person consumes in a given period, the higher is her subsequent habit stock. The parameter γ represents how quickly the person develops (and eliminates) her habit.

We assume that instantaneous utility takes a particularly simple functional form:

14. The early literature on habit formation distinguishes between two polar cases: "rational habits" wherein consumers fully account for how current consumption affects future well-being, and "myopic habits" wherein consumers do not account at all for how current consumption affects future well-being. Of the papers cited in the text, all assume rational habits except for Pollak [1970], which (implicitly) assumes myopic habits. Our model is equivalent to rational habits when $\alpha = 0$ and to myopic habits when $\alpha = 1$. Muellbauer [1988] provides an excellent overview of the two extremes, and concludes that the empirical evidence seems to favor myopic habits. We return to this and other empirical evidence in Section VI.

$$u(c_t,s_t) = v(c_t - s_t), \qquad \text{where } v' > 0 \text{ and } v'' < 0.$$

This formulation is potentially restrictive, but it captures the key feature of habit formation and is common in the literature.[15] There are actually two key features that play a role in our results below. First, the marginal utility from consumption is increasing in the habit stock ($\partial[\partial u/\partial c]/\partial s > 0$), which implies habit formation—an increase in current consumption increases the future habit stock and therefore increases the marginal utility from future consumption. Second, the level of utility is declining in the habit stock ($\partial u/\partial s < 0$), which implies that an increase in current consumption reduces the utility from future consumption. Although this negative "internality" [Herrnstein et al. 1993] is not an inherent part of habit formation, it is present in most formal analyses, and real-world instances, of habit formation.

In period 1 the person faces the following choice problem, where s_1 is exogenous:

$$\max_{(c_1, \ldots, c_T)} \tilde{U}^1(c_1, \ldots, c_T|s_1) = \sum_{\tau=1}^{T} [(1-\alpha)v(c_\tau - s_\tau) + \alpha v(c_\tau - s_1)]$$

such that

$$s_t = (1-\gamma)s_{t-1} + \gamma c_{t-1} \text{ for } t \in \{2, \ldots, T\} \qquad \text{and} \qquad \sum_{\tau=1}^{T} c_\tau \le Y.$$

For ease of presentation, let $(c_1^*, \ldots, c_T^*)$ denote rational behavior, which solves this maximization when $\alpha = 0$, and let $(c_1^A, \ldots, c_T^A)$ denote planned behavior from the period 1 perspective for a person with $\alpha > 0$, with the value of α suppressed in the notation. Our analysis throughout assumes interior solutions for both rational and actual behavior.

A pattern typically emphasized in models of habit formation is that people choose an increasing consumption profile—that is, $c_1 < \ldots < c_T$—so that they are always consuming more than

15. This formulation is equivalent to that used by Pollak [1970], Constantinides [1990], Jermann [1998], Campbell and Cochrane [1999], and Boldrin, Christiano, and Fisher [2001]; indeed, all these papers except Pollak further assume that v takes a CRRA specification. Another formulation, proposed by Abel [1990] and used by Fuhrer [2000] and Carroll, Overland, and Weil [2000], is $u(c_t,s_t) = (c_t/s_t^\gamma)^{1-\sigma}/(1-\sigma)$. Yet a third formulation, suggested by Kahneman and Tversky's [1979] prospect theory, is to assume that $v''(x) < 0$ for $x > 0$ but $v''(x) > 0$ for $x < 0$; Bowman, Minehart, and Rabin [1999] use a variant of this approach.

they are accustomed to. This conclusion holds, however, only if the person's initial habit stock s_1 is not too large. Otherwise, it might be optimal to break the initial habit, and the optimal way to do so might involve a declining consumption path that lowers the habit stock gradually over time.[16] But since breaking a habit is both least painful and most beneficial when done early in life, before the habit has been further developed and when the benefits will be spread over a large number of years, a rational person will break a habit only at the beginning of life. Lemma 1 formally establishes this conclusion by demonstrating that once a person starts further developing her habit—by consuming more than her habit stock—she will follow an increasing consumption profile from that period onward.

LEMMA 1. If $c^*_\tau \geq s^*_\tau$ for some $\tau < T$, then $c^*_\tau < c^*_{\tau+1} < \ldots < c^*_T$.

We focus on the implications of projection bias for situations in which rational behavior does not involve early-life habit-breaking episodes: our results below only apply to parameter values such that a rational person would choose an increasing consumption profile. Lemma 1 implies that a sufficient condition for a rational person to choose an increasing consumption profile is $s_1 = 0$; more generally, this outcome will occur as long as the initial habit stock s_1 is small enough.

Projection bias creates two types of distortions in this environment, because the person underappreciates both the negative internality and the habit formation. The implication of projection bias over the negative internality is straightforward. Because it implies that early consumption decreases utility in all later periods, the negative internality motivates a person to delay consumption. Hence, an underappreciation of the negative internality makes the person prone to consume too much early in life and too little late in life relative to rational behavior. The implication of projection bias over habit formation is in principle more complicated because the basic effect of habit formation is complicated. But for the case in which rational behavior does not involve a habit-breaking episode, and therefore involves an increasing consumption profile, the person's habit stock will be increasing over time, and therefore habit formation makes her marginal utility

16. Indeed, for $s_1 > Y/T$ the person *must* have a habit-breaking episode, and this episode might last her entire life; that is, she might have $c^*_1 > c^*_2 > \ldots > c^*_T$.

increase over time. As a result, habit formation also motivates the person to delay consumption. Hence, an underappreciation of habit formation, like an underappreciation of the negative internality, makes the person prone to consume too much early in life and too little late in life relative to rational behavior. Proposition 1 reflects this intuition, establishing that whenever rational behavior does not involve a habit-breaking episode, projection bias leads a person to (plan to) consume too much early in life and too little late in life relative to what would be optimal.

PROPOSITION 1. If $c_1^* \geq s_1$, then for any $\alpha > 0$, $\Sigma_{t=1}^{\tau} c_t^A > \Sigma_{t=1}^{\tau} c_t^*$ for all $\tau < T$.

Hence, projection bias causes a person to plan a consumption profile that consumes her income too quickly. Perhaps the cleanest illustration is in the extreme case where $\alpha = 1$, where the person will plan to consume the same amount in all periods rather than increase consumption over time as would be optimal.[17]

More interesting is what happens as time passes and the person's tastes change in ways she did not predict. To study such effects, we examine how a person's plans change in period 2. In period 2 the person reoptimizes given her new perceived preferences; that is, she faces the following choice problem, where s_1 and c_1^A are exogenous:

$$\max_{(c_2, \ldots, c_T)} \tilde{U}^2(c_2, \ldots, c_T | s_2) = \sum_{\tau=2}^{T} [(1 - \alpha)v(c_\tau - s_\tau) + \alpha v(c_\tau - s_2)]$$

such that

$$s_2 = (1 - \gamma)s_1 + \gamma c_1^A$$
$$s_t = (1 - \gamma)s_{t-1} + \gamma c_{t-1} \text{ for } t \in \{3, \ldots, T\}$$
$$\text{and} \quad \sum_{\tau=2}^{T} c_\tau \leq Y - c_1^A.$$

17. While the assumption that rational behavior does not involve a habit-breaking episode is sufficient for overconsumption, it is not necessary. Proposition 1 might fail because, during a habit-breaking episode, habit formation and a declining habit stock mean the person's marginal utility declines over time, which in turn means that habit formation motivates the person to accelerate consumption, and so projection bias over habit formation leads the person to consume her income too slowly. But Proposition 1 need not fail, because projection bias over the negative internality still motivates the person to consume her income too quickly.

Rational behavior, of course, does not change over time, and hence the solution to this problem for $\alpha = 0$ is $(c_2^*, \ldots, c_T^*)$. For a person with projection bias, the solution for this problem, which we denote by $(c_2^{AA}, \ldots, c_T^{AA})$, may differ from her period 1 plans $(c_2^A, \ldots, c_T^A)$. Proposition 2 characterizes this revision of plans in the case where she is developing a habit and $T = 3$.

PROPOSITION 2. Suppose that $T = 3$ and $c_1^A > s_1$. Then $v''' > 0$ implies that $c_2^{AA} > c_2^A$, $v''' < 0$ implies that $c_2^{AA} < c_2^A$, and $v''' = 0$ implies that $c_2^{AA} = c_2^A$.

As the person's habit stock changes over time, her (perceived) marginal utilities from consumption in each period also change. When the person is developing a habit, these marginal utilities all increase.[18] Hence, the relative magnitudes of these changes in marginal utility determine the revision of plans. If $v''' = 0$, the increase in marginal utility is the same for all periods, which implies that the person's marginal trade-offs have not changed, and hence she does not revise her consumption plan. If $v''' > 0$, the increase in marginal utility is larger for period 2 than period 3, and as a result she revises her period 2 consumption upward. If $v''' < 0$, the increase in marginal utility is smaller for period 2, and she revises her period 2 consumption downward.[19]

Any utility function that satisfies nonincreasing absolute risk aversion, which includes the CARA and CRRA families, must have $v''' > 0$. Because this seems a plausible restriction on the instantaneous utility function, Proposition 2 suggests that projection bias leads people to repeatedly readjust their immediate consumption upwards relative to their most recent plans. Hence, if people experience habit formation in consumption, projection bias represents a possible source for actual saving being smaller than planned saving. Laibson, Repetto, and Tobacman [1998]

18. Formally, from a period t perspective, the (perceived) marginal utility from period 2 consumption is $(1 - \alpha)v'(c_2 - s_2) + \alpha v'(c_2 - s_t) + (1 - \alpha)\gamma v'(c_3 - s_3)$; and since $s_2 > s_1$ implies that $v'(c_2 - s_2) > v'(c_2 - s_1)$, this marginal utility is larger from a period 2 perspective. Similarly, from a period t perspective, the (perceived) marginal utility from period 3 consumption is $(1 - \alpha)v'(c_3 - s_3) + \alpha v'(c_3 - s_t)$; and since $s_2 > s_1$ implies that $v'(c_3 - s_2) > v'(c_3 - s_1)$, this marginal utility is also larger from a period 2 perspective.

19. We conjecture, but have not proved, that this conclusion holds for $T > 3$. The result that $v''' = 0$ yields dynamic consistency is quite general. For the case $v''' > 0$, it is straightforward to show that marginal utility increases most for period 2 and least for period T, and so, perhaps subject to additional regularity conditions, after reoptimization we should expect period 2 consumption to increase and period T consumption to decrease. Analogous conclusions hold for the $v''' < 0$ case.

review considerable evidence that the actual saving of many households falls short of their plans. The authors posit self-control problems and naivete about those self-control problems as primary sources of this shortfall. Our analysis suggests that projection bias, in the form of underappreciation of how increasing consumption in the present will raise one's consumption standard in the future, might also contribute to such mispredictions.

While our analysis assumes that a person's lifetime income is exogenous, our model suggests implications for how projection bias might influence decisions about how hard to work to increase income. Specifically, let λ^A be the marginal utility of lifetime income as perceived from period 1, and let λ^{AA} be the marginal utility of lifetime income as perceived from period 2. Again limiting ourselves to the case when a person is developing a habit and the horizon is $T = 3$, Proposition 3 establishes that the marginal utility of lifetime income increases over time.

PROPOSITION 3. Suppose that $T = 3$ and $c_1^A > s_1$. Then $\lambda^{AA} > \lambda^A$.

Proposition 3 reflects a simple intuition: as time passes, and the person's real and perceived marginal utilities from consumption increase, income becomes more valuable. Extrapolating beyond our formal framework, this result suggests that projection bias over habit formation might lead people to pursue higher income than planned as time passes. Projection bias might, for instance, create a force toward choosing a later and later planned retirement date as time passes, using the proceeds to increase consumption.[20] Similarly, with endogenous per-period labor-leisure decisions, projection bias might create a tendency to repeatedly increase labor and decrease leisure relative to earlier plans. We are wary of pushing this intuition too far without further theoretical and empirical analysis, however, because the logic of the argument assumes that there is no reference dependence in leisure. But we do note that this intuition parallels the arguments of many previous researchers, such as Scitovsky [1976] and Frank [1999], who have argued that people spend too much time and energy generating wealth and too little time on leisure activities, and that people enjoy increases in their material consumption less than they think they will.

20. There is some evidence, however, that people are somewhat accurate at predicting their retirement dates (see Bernheim [1989]), although this may in part be due to the existence of focal retirement ages.

V. Projection Bias and Durable Goods

For most durable goods—such as a tent, a golf-swing trainer, or a Johnny Depp video—people experience day-to-day fluctuations in their valuations. For rational consumers, such fluctuations are virtually irrelevant, because they will purchase durable goods based almost exclusively on their expected daily valuations for the goods, and virtually ignore their valuations on the day they happen to be in the store. But for people with projection bias, buying decisions are oversensitive to the momentary feelings they experience when they happen to be in the store, and thus the nature of day-to-day fluctuations becomes important. In this section we present a stylized model that identifies some implications of such effects.

Suppose that a person's valuation of a durable good in period τ is given by a random variable μ_τ, where μ_τ is distributed identically and independently across periods, and has finite mean $\bar{\mu}$. The person learns the realization of μ_τ at the start of period τ. For simplicity, we further assume that the durable good lasts for exactly D days, and that the person cannot consume the good on the day she purchases it.[21]

Consider first a consumer who has just one opportunity, on day 1, to purchase the item; if she does not purchase it on day 1, she cannot purchase it at all. We normalize the person's intertemporal utility to be zero when she does not buy the product. If she buys the product at price P, she will enjoy the benefits of ownership, but must forgo the consumption of other goods that she could have financed with wealth P.[22] We assume that the person's utility from the durable good is additively separable from her utility for other goods, and that the price P represents the total utility value of the other goods forgone by purchasing the durable good. The person's state in period τ is her current valuation, or $s_\tau = \mu_\tau$. Finally, we assume that there is no discounting, or $\delta = 1$; none of our conclusions depend on this assumption.

If the person buys the durable good in period 1, then, given

21. While it is often unrealistic to assume that the person cannot consume the good on the day she purchases it, none of our qualitative conclusions depend on this assumption, and it vastly simplifies our analysis.

22. We take the price P to be exogenous. In Loewenstein, O'Donoghue, and Rabin [2000] we formulate a more complicated model that derives a monopolist's pricing and valuation-changing sales-hype policies in the face of projection bias by consumers.

the information available, her true expected intertemporal utility is

$$E_1[U^1] = E_1\left[\sum_{k=1}^{D} \mu_{1+k} - P\right] = D\bar{\mu} - P.$$

A person exhibiting simple projection bias perceives her expected intertemporal utility to be

$$E_1[\tilde{U}^1] = E_1\left[\sum_{k=1}^{D} [(1-\alpha)\mu_{1+k} + \alpha\mu_1] - P\right]$$
$$= D\bar{\mu} + \alpha D(\mu_1 - \bar{\mu}) - P.$$

$\mu_1 > \bar{\mu}$ implies that $E_1[\tilde{U}^1] > E_1[U^1]$, and $\mu_1 < \bar{\mu}$ implies that $E_1[\tilde{U}^1] < E_1[U^1]$. Hence, an underappreciation of day-to-day fluctuations can lead variously to underbuying or overbuying. If her day 1 valuation is larger than average, and she projects this above-average valuation onto the future, the person is prone to overvalue the durable good. If, in contrast, her day 1 valuation is smaller than average, and she projects this below-average valuation onto the future, she is prone to undervalue the durable good. In other words, a person with projection bias is too sensitive to her valuation at purchase time.[23]

While projection bias has ambiguous effects in one-shot buying decisions, things change dramatically in the more realistic case where the person has multiple opportunities to buy a durable good. To make this point in a particularly stark way, we suppose that the consumer will purchase the good at most once, and can buy the good in any period $t \in \{1, 2, \ldots\}$. In this situation a rational person either will buy the durable good immediately in period 1 or never buy the durable good, and she buys the durable good if and only if $D\bar{\mu} - P \geq 0$. Intuitively, given our assumption that the person cannot consume the good on the day she purchases it, the net expected value of the durable good is

23. If we allowed immediate consumption, a rational type would also be sensitive to her day 1 valuation. But a projector would still be oversensitive to her day 1 valuation: indeed, the conclusion generalizes that an underappreciation of day-to-day fluctuations leads a person to overvalue the good when $\mu_1 > \bar{\mu}$ and undervalue it when $\mu_1 < \bar{\mu}$.

independent of the valuation on the date purchased. Hence, the good is either worth purchasing immediately or not at all.[24]

A person with projection bias, like a rational person, always *perceives* that the good is either worth purchasing immediately or not at all. But her perception of whether it is worth purchasing immediately is influenced by her current valuation. As a result, she ends up purchasing the good in the first period that $D\bar{\mu} + \alpha D(\mu_\tau - \bar{\mu}) - P \geq 0$. If we let μ_H denote the largest value that μ_τ might possibly take on, then there will eventually be some period in which the person perceives the good to be worth purchasing if and only if $D\bar{\mu} + \alpha D(\mu_H - \bar{\mu}) - P > 0$. Because $\mu_H > \bar{\mu}$, a person with projection bias is unambiguously more prone to buy the durable good than is a rational person: she will always buy when she should buy, and sometimes when she should not.

The intuition behind this conclusion is an inherent asymmetry in purchases of durable goods. A decision not to buy is reversible, so if the person does not buy today when she should, she can still buy in the future. But a decision to buy is irreversible, so if she buys today when she should not, she cannot unbuy in the future. With multiple buying opportunities, a person is prone not to buy when she should only in the unlikely event that she has a particularly low valuation *on every* buying opportunity, whereas she is prone to buy when she should not in the quite likely event that she has a particularly high valuation *on at least one* buying opportunity. Hence, projection bias represents a source of "impulse purchases" wherein people overbuy durable goods in response to transitory desire for that good. Many prior theoretical treatments of impulse purchases have attributed the phenomena to hyperbolic discounting. But for durable goods, projection bias is more relevant than hyperbolic discounting. Hyperbolic discounting provides a compelling explanation for overconsumption on cumulative small-scale consumption decisions, such as purchases of potato chips, where the net effects of repeated purchases can be vast overconsumption of potato chips. The purchase of a durable good, however, is by its very nature a long-term-consumption decision. As such, self-control problems are *less* likely to be implicated in the purchase of durable than nondurable goods, whereas projection bias is more likely to be implicated.

24. Formally, we assume that when indifferent between buying now versus buying in the future, people choose to buy now (which would be optimal if we replace $\delta = 1$ with $\delta < 1$ but very close to 1).

Our analysis suggests that certain types of sales tactics might be understood as attempts by businesses to exploit projection bias. If consumers overestimate the longevity of their current feelings, sellers will have an incentive to induce high valuations when people are making buying decisions, via sales hype, enticing displays, or mood-inducing music. Sellers will also have an incentive to pressure people to make purchase decisions when hot, and to facilitate rapid purchases by consumers who are in a hot state that is unlikely to last, such as one-click shopping on the internet. Finally, projection bias might motivate firms to turn nondurable goods into durable goods via "intertemporal bundling," e.g., selling memberships in health clubs, golf clubs, vacation time shares, or season ski passes. Consider, for instance, a person who becomes enthusiastic about exercise and makes a visit to a health club. Rather than making a profit solely on that one visit, the health club may exploit the consumer's tendency to project her current enthusiasm into the future by offering a more expensive "club membership" that entitles the person to additional free (or low-cost) visits in the future. Indeed, Della Vigna and Malmendier [2002] empirically document that people overpay for health club memberships. Using a panel data set that tracks members of three New England health clubs, they find that members who chose a contract with a flat monthly fee paid a price per visit of $17, and members who chose a contract with a flat yearly fee paid a price per visit of $15, even though a $10-per-visit contract was also available. Della Vigna and Malmendier attribute these findings to partially naive self-control problems: people sign up in an attempt to "commit" themselves to future exercise, but then do not have enough self-control to carry out these plans. Our model suggests an additional possible explanation: people plan to attend frequently because they project their current enthusiasm into the future, but then decide not to attend in the future when their enthusiasm has waned.[25]

In addition to helping to explain sales tactics, our analysis may also shed light on laws designed to counteract them. Cooling-off laws enacted at both the state and federal level allow consumers to rescind certain types of purchases within a few days of the

25. We suspect that another contributory factor is that people dislike paying on the margin for consumption [Prelec and Loewenstein 1998]. Neither this nor projection bias is likely to explain Della Vigna and Malmendier's evidence of procrastination in canceling memberships, which is more consistent with naive self-control problems.

transaction.[26] Such laws can be viewed as devices for combatting the effects of projection bias. Cooling-off periods that force consumers to reflect on their decisions for several days can decrease the likelihood that they end up owning products that they should not. Cooling-off laws may also have the benefit of reducing salespersons' incentives to hype. If consumers can return products once they cool down and if such returns are costly for the seller, sellers will have an incentive to put buyers in a long-run average mood rather than an overenthusiastic state.

Although our analysis focuses solely on random fluctuations in tastes, more generally durable goods might involve other types of taste changes. Projection bias over such changes could yield further interesting conclusions. For some durable goods, a person's valuation systematically declines over time as the "novelty" wears off. Projection bias over such taste changes would create a tendency to overbuy, and hence firms might engage in attempts to create increased feelings of novelty. Alternatively, for other durable goods, a person's valuation increases over time as the person develops a taste for the good (or becomes attached to the good). Projection bias over these taste changes would create a tendency to underbuy. In such cases firms might, in fact, engage in behaviors designed to overcome projection bias, such as offering a free-trial period.

VI. Other Applications

Sections IV and V derive the implications of projection bias in two specific economic environments. These implications highlight two types of errors to which projection bias can give rise. First, the failure to predict future taste changes can lead to misguided choices for current consumption, e.g., overconsumption due to underappreciation of habit formation, and oversensitivity to current valuations as a result of exaggerating the longevity of day-to-day fluctuations in tastes. Second, as perceived tastes change over time in ways that people do not predict, people make plans that they may end up not carrying out; e.g., people may consume more (and save less) than earlier planned. We believe that projection bias is important for many economic applications, and that it can provide an intuitive and parsimonious account for many phenomena that are otherwise difficult to explain. In this

26. For a detailed discussion of such laws, see Camerer et al. [2003].

section we extrapolate from our formal analysis in Sections IV and V to discuss additional implications of projection bias.

There are many implications of projection bias for recent models of habit formation beyond the formal analysis in Section IV. In recent years economists have often invoked habit formation in consumption as an explanation for empirical phenomena that are hard to understand within a stationary-utility framework. As we discuss in Section IV, for instance, habit formation is sometimes invoked as an explanation for why people choose consumption profiles that increase over time. In addition, Constantinides [1990] argues that habit formation can provide an explanation for the equity-premium puzzle, because it leads people to expect to maintain high levels of risk aversion even with rising levels of consumption and wealth (see also Abel [1990] and Campbell and Cochrane [1999]). Fuhrer [2000] shows that habit formation might explain the "excess smoothness" of consumption (documented by Campbell and Deaton [1989]) and Carroll, Overland, and Weil [2000] demonstrate that habit formation can explain recent empirical evidence that periods of high aggregate income growth seem to cause periods of high aggregate saving. These explanations derive from the fact that, because people expect to adapt to their changing consumption levels, they adjust slowly to shocks to their permanent income.

Habit formation is a compelling explanation for these phenomena, because it accords well with introspection and common wisdom, and is consistent with psychological evidence on adaptation. Even so, it has been hard to find direct evidence of habit formation in time-series consumption data. Dynan [2000] reviews the mixed results from tests using aggregate consumption data, and describes how such tests might be prone to overstate the degree of habit formation. Dynan then tests for habit formation using household data on food consumption, and finds no evidence of habit formation. Our model suggests an explanation: even if people are characterized by habit formation, projection bias may lead people to not react to that habit formation as strongly as the rational model suggests. Indeed, in our simple eat-the-cake model, we saw exactly this point: whereas introducing habit formation would lead rational consumers to switch from smooth consumption to an increasing consumption profile, projection bias undermines this effect. In fact, for a person with complete projection bias, or $\alpha = 1$, the introduction of habit formation does not change her behavior at all. Muellbauer [1988] makes a similar point when he compares rational versus myopic habits—which is equivalent to $\alpha = 0$ and $\alpha = 1$ in our model. Specifically, he points out that habit formation would show up in cross-sectional evidence under either assumption, but it would show up in time-series evidence only under the assumption of rational habits. Given that it is hard to find evidence of habit formation in time-series evidence, Muellbauer concludes that the evidence supports myopic habits.

Hence, perhaps a better hypothesis is that people are characterized by a combination of habit formation and projection bias. If so, our model suggests where to look for additional evidence. Specifically, it predicts specific patterns of dynamic inconsistency. We already described one such prediction in Section IV: people with projection bias over habit formation will plan to save more in the future than they actually end up saving (under the plausible assumption of nonincreasing absolute risk aversion). Extrapolating from our model, an additional area on which there might be dynamic inconsistency is charitable giving. Charitable giving depends on a trade-off between the benefits of giving and the cost of forgone personal consumption. While the marginal utility of consumption may decline with wealth, habit formation reduces the magnitude of this change. As a result, people with projection bias may plan to increase their charitable giving as their wealth increases by more than they actually end up doing.[27]

An obvious application of projection bias is addiction. Rational-choice models of addiction provide plausible explanations for many different patterns associated with addiction, but often have difficulty accounting for the most central problem: why do people become addicted in the first place? Because habit formation is a natural way to formalize "addictiveness"—indeed most models of addiction use this formulation—our analysis in Section IV suggests two reasons why people with projection bias might be over-prone to develop harmful addictions. First, projection bias may lead people to underappreciate the degree to which current consumption has negative consequences for their future health, employment, and personal lives; that is, they may underappreciate

27. A difficulty with identifying projection bias via dynamic inconsistency is that there are other sources of dynamic inconsistency, such as naive hyperbolic discounting. Here, saving less than planned and giving less than planned also seem consistent with naive hyperbolic discounting; but in fact one can distinguish the two sources because of the asymmetry in the predictions. Projection bias predicts saving less than planned and giving less than planned when wealth is increasing, but the opposite effects when wealth is declining.

the negative internality associated with addictive products. Second, and perhaps more important, projection bias may lead people to underappreciate the degree to which current consumption changes their future desire for addictive products; that is, they may underappreciate the habit formation associated with addictive products. This second error is particularly pernicious because it can lead people to consume addictive products in the short run, planning not to continue in the long run, but then end up becoming addicted.[28]

Our analysis in Section V of day-to-day fluctuations in tastes is also relevant for addiction. In particular, it suggests that people might overreact to transitory changes in the craving for addictive products. When a person's craving is particularly high, projection bias will lead her to overestimate her future craving for the drug, and therefore may discourage her from any efforts to quit. Analogously, when her craving is particularly low, projection bias will lead her to underestimate her future craving for the drug, and therefore may cause her to make repeated painful efforts to quit only to fail in these endeavors when her craving returns to average or high levels. There is, in fact, empirical support for addicts believing that their future craving will be similar to their current craving. Giordano et al. [2001] studied heroin addicts who came to a clinic for a maintenance dose of Buprenorphine (similar to methadone). These addicts were asked to choose between extra BUP or extra cash on a visit scheduled for five days later, where half were given the choice right before receiving the BUP and half were given the choice right after. Those making the choice before receiving the BUP valued the future BUP dose by almost twice as much as those who made the choice after receiving the BUP.

28. There is, in fact, evidence that unaddicted cigarette smokers significantly underappreciate their own risk of becoming addicted. For instance, only 15 percent of high school students who were occasional smokers (less than one cigarette per day) predicted that they might be smoking in five years, when in fact 42 percent were still smoking five years later, and 28 percent were daily smokers. But there is also evidence that *addicted* cigarette smokers underappreciate their risk of staying addicted. For instance, 68 percent of high school students who were heavy smokers (more than one pack per day) predicted that they would still be smoking in five years, while 80 percent were still smoking at least half a pack per day five years later [U. S. DHHS 1994]. The mispredictions of occasional smokers are arguably larger than those for heavy smokers, and even the mispredictions of heavy smokers could be due to projection bias if they made predictions while in a nicotine-sated state. Even so, the average mispredictions of heavy smokers suggests that the mispredictions of even the occasional smokers might in part be due to overoptimism about self-control or other factors rather than projection bias.

Projection bias over the endowment effect has further implications (beyond those in Section II). The usual explanation for the endowment effect is that people adapt to owning or not owning objects, and that there is more pain upon parting with objects than there is joy upon obtaining objects. Projection bias over this adaptation has several interesting implications. First, because projection bias leads to exaggerated feelings of loss aversion, it magnifies the size of the endowment effect. In other words, while the endowment effect may be caused by valid expectations that losses will hurt more than gains will help, the endowment effect that we observe in experiments may be an exaggerated response to these real preferences.[29] Perhaps more important is that people may fail to predict the endowment effect. At a purely individual level, this failure can lead individuals to make purchases with a false sense of their reversibility, and undoubtedly lowers the cost to retailers of offering money-back guarantees and free returns. In bilateral economic transactions, it can cause distortions or break down in bargaining, because buyers will tend to underestimate owners' reservation prices, and owners will tend to overestimate buyers' reservation prices. Indeed, Van Boven, Dunning, and Loewenstein [2000] experimentally demonstrate bargaining inefficiency due to "buyers' agents" underestimating sellers' reservation values.[30]

As highlighted by our analysis in Section V, projection bias predicts suboptimal patterns of behavior when people make decisions with long-term consequences but experience highly variable day-to-day feelings. While our formal analysis concerned durable goods, more important life decisions such as marriage, divorce, and especially fertility all display such a pattern. For such long-term decisions, momentary fluctuations in feelings should be virtually irrelevant, but projection bias will cause people to exaggerate their longevity and therefore to give them too

29. Kahneman [1991, p. 143] and Tversky and Kahneman [1991] argue that the endowment effect is a "bias" because people's actual pain when losing an object is not commensurate with their unwillingness to part with that object. Evidence from Strahilevitz and Loewenstein [1998] supports this interpretation. Loewenstein, O'Donoghue, and Rabin [2002] present a detailed analysis of the role of projection bias in the endowment effect.

30. Also see Genesove and Mayer [2001], who find evidence of financial loss aversion in housing markets—of people experiencing "pain" when they realize a nominal loss on their home. In particular, they find that sellers subject to nominal losses set higher asking prices and exhibit a lower hazard rate of sale. Projection bias suggests that the magnitudes of these effects may be larger than justified by any true feelings of pain that people experience if and when they do sell their residence at a loss.

much weight in their decisions. Hence, projection bias might lead people to get married—or make proposals of marriage that are costly to rescind—in the thralls of love, say things they later wish they had not in a fit of rage, and fail to use birth control or to follow safe sex practices in the heat of passion. There are, in fact, policies that seek to circumvent such tendencies: for example, in many states there are mandatory time delays between filing for marriage or divorce and actual changes in status. And there seems to be a demand for methods of birth control that allow one to control fertility without making decisions in the heat of passion, such as Norplant and the "morning after" pill.

Whereas marriage, divorce, and fertility decisions are difficult to reverse, suicide is totally irreversible. Yet much suicidal behavior seems to occur on impulse, or after only a relatively short period of misery. Projection bias may well contribute to this phenomenon. The literature on depression documents a tendency for people who are depressed to project their depressed feelings not only on the future, but also on the past. As Solomon [1998, p. 49] expresses it, "When you are depressed, the past and the future are absorbed entirely by the present. . . . You can neither remember feeling better nor imagine that you will feel better." Other research documents that the will to live varies dramatically over time. In a study of 168 cancer patients admitted to a hospital for end-of-life care, the patients' will to live, as measured on a 100-point scale, fluctuated an average of 30 percent over a 12-hour period and more than 60 percent over a 30-day period [Chochinov et al. 1999].

The combination of such fluctuations and projection bias also has important ramifications for end-of-life care, in particular for the use of mechanisms such as "advanced directives" and "living wills" that permit people to make decisions that will apply when they are in a health state that renders them unable to make decisions for themselves. The premise of such tools is that healthy people can make decisions that will reflect their own preferences when sick, but the presence of projection bias would challenge the validity of this assumption (see Coppola et al. [1999] and Druley et al. [1993]). Indeed, in one study [Slevin et al. 1988], respondents were asked whether they would accept a grueling course of chemotherapy if it would extend their lives by three months. While only 10 percent of healthy people said that they would accept the chemotherapy, 42 percent of current cancer patients say they would. A natural interpretation is that the value of a day of life is larger when the prospect of death is close at hand, but projection bias leads people to underappreciate this change.

Projection bias also has further implications in the mundane world of consumer theory. Although economists usually capture satiation with a static model that assumes diminishing marginal utility, we usually have in mind a dynamic notion that the utility of current consumption depends on recent consumption. The satisfaction from eating a pint of ice cream is smaller if one has just consumed another pint of ice cream. The satisfaction from eating salmon is smaller if one has already consumed salmon for several evenings in a row. Projection bias over such effects has diverse consequences. Most straightforwardly, it leads to overconsumption, or at least overordering of appetite-dependent goods. More generally, people may be prone to overpurchase activities that they currently do not engage in. People may plan overly long vacations, believing the ninth day lying on the beach will be nearly as enjoyable as the first; and professionals who have little time for reading or traveling may falsely anticipate the blissfulness of spending their retirement years with nonstop reading and traveling. Firms may, of course, take advantage of such mispredictions, by selling large quantities in advance; restaurants may take advantage of projection bias by offering all-you-can-eat meals to hungry diners who underestimate how quickly they will become satiated.

We conclude with perhaps the broadest implication of projection bias: much as in the opening quotation from Adam Smith, projection bias will lead to a general "over-rating the difference between one permanent situation and another." Projection bias over habit formation, for instance, can lead people to overrate the differences between "poverty and riches." In simple terms, poor people will overestimate how good it would be to become rich, and rich people will overestimate how bad it would be to become poor. Perhaps more important, because projection bias makes people mispredict how they themselves would behave in other situations, it can lead to misunderstandings between these two groups of people. For instance, projection bias can lead low-wealth individuals to find the behavior of wealthy individuals reprehensible because they expect the rich to engage in more charitable giving than they actually do.

Although on a smaller scale, there is experimental evidence of such misunderstandings between groups. As mentioned above with regard to projection bias over the endowment effect, Van

Boven, Dunning, and Loewenstein [2000] experimentally demonstrate bargaining inefficiency due to "buyers' agents" underestimating sellers' reservation values. They further show that when the buyers' agents were asked to explain the high prices of the sellers, they rejected explanations that resembled the endowment effect in favor of explanations that hinged on greed on the part of the sellers. Much in the same way that the rich might seem greedy to the poor, projection bias over the endowment effect can lead to negative judgments of other people's characters. To the extent that such negative judgments might make people willing to incur losses to hurt others [Gibbons and Van Boven 2001; Loewenstein, Thompson, and Bazerman 1989], projection bias might have both direct and indirect consequences in everyday economic behavior.

Smith also suggests that people are likely to exaggerate the importance between "private and public station," i.e., social status. In recent years, social-comparison theory, which studies the ways a person cares about her status relative to comparison groups, has received increasing attention from economists. When people make decisions that cause their comparison groups to change—such as switching jobs or buying a house in a new neighborhood—projection bias predicts that people will underappreciate the effects of a change in comparison groups and hence, consistent with Smith's assertion, overestimate the long-term satisfaction that would accompany such a change. As a result, people may be too prone to make reference-group-changing decisions that give them a sensation of status relative to their current reference group. If a person buys a small house in a wealthy neighborhood in part because it has a certain status value in her apartment building, she may not fully appreciate that her frame of reference may quickly become the larger houses and bigger cars that her new neighbors have.

VII. Discussion and Conclusion

Our goal in this paper has been to introduce a formal model that can improve the realism of the economic analysis of intertemporal decision-making by incorporating a common form of misprediction of future preferences. The psychological evidence presented in Section II provides support for the existence of projection bias, and our analysis and discussion in Sections IV, V, and VI demonstrate the potential importance of projection bias for economics. We conclude by putting projection bias in broader economic context, and discussing some shortcomings and potential extensions of our model.

How might one empirically identify projection bias in economic data? According to our model, while people may be wrong in their predicted utility, they still obey the axioms of "rational" choice in one-shot decisions: they have well-defined predicted preferences and make decisions to maximize those preferences.[31] Hence, if all we observe is a single decision by each person, projection bias may be difficult to identify, except insofar as we can find field-data analogues of Read and van Leeuwen's [1998] experiments—instances in which people's current state plays "too large" a role in their decisions. However, if we observe multiple observations for each decision-maker, researchers can identify projection bias through dynamic inconsistency. We might compare directly people's plans and their later behavior, as in the Loewenstein and Adler [1995] experiments. Or we might indirectly infer dynamic inconsistency from intertemporal behavior, as in the health-club evidence from Della Vigna and Malmendier [2002].[32]

Our review of evidence and our analysis in this paper leave a number of open questions. One is the extent to which projection bias diminishes with experience. That projection bias operates on states, such as hunger, with which people should have ample experience suggests that it does not disappear with experience. Moreover, an explicit test of the effect of repeated experience failed to produce any appreciable learning [Van Boven, Loewenstein, and Dunning 2003]. In this study, "buyers' agents"—with incentives to facilitate exchange but at the lowest possible price—made take-it-or-leave-it offers for an object to sellers. There were five rounds of possible trade, with feedback after each round about whether the bids were too high or too low. Bids, which were initially too low due to buyers' agents' underappreciation of sellers' attachments to objects, increased over the five rounds, and converged toward the profit-maximizing level. However, when a

31. Kahneman [1994] distinguishes between "experienced utility," which reflects one's welfare, and "decision utility," which reflects the attractiveness of options as inferred from one's decisions; projection bias represents a reason why decision utility may deviate from experienced utility.

32. When we observe dynamic inconsistency, the question arises whether the source is projection bias or some other error, such as naive hyperbolic discounting. But as we discuss in footnote 27, it is often possible to find situations where different behavioral errors predict different types of dynamic inconsistency.

new object of similar value was substituted for the original object, the same pattern occurred. Subjects learned to adjust their bids upward, but they did not learn to anticipate the endowment effect.

A related second open question is how aware are people of the bias. The existence of advice such as "count to ten before you respond" or "never shop on an empty stomach" suggests that people are aware of projection bias on a meta-level. In addition, we suspect that many rules people develop are designed to deal with moment-by-moment projection bias. For instance, in the context of our durable-good model, people might develop rules such as never buy a car on a first visit to a dealer. The need for such rules provides further evidence that people suffer from projection bias, but also implies that its damaging effects may be mitigated in many circumstances.

A third open question concerns our treatment of projection bias as a pure error. We believe that perhaps the most important reason to incorporate projection bias into economics is to improve welfare analysis (rather than solely to improve behavioral predictions)—to study, for instance, whether addicts are making an optimal lifetime decision to become addicts. As such, we have emphasized the ways in which people behave suboptimally. There may, however, be reasons to be more cautious about treating all changes in behavior as suboptimal.[33]

As models that reflect the reality of both short-term fluctuations and long-term changes in preferences become more widespread in economics, economists must seriously address the question of whether people accurately predict how their preferences will change. We hope our analysis and examples illustrate the potential benefits for both behavioral and welfare economics of incorporating mispredictions of utilities in general, and projection bias in particular, into formal economic analysis.

33. Projection bias might, for instance, serve the interests of the human race to the detriment of the individual; e.g., the failure to appreciate adaptation to paraplegia or blindness may help to limit the number of disabled people in the population. A full normative analysis should, as always, take into account such externalities, and it is possible that projection bias mitigates them. Similarly, at the individual level it is possible that projection bias serves to mitigate other errors; e.g., to work against factors such as self-control problems or underappreciation of risks that might cause people to exert too little effort at avoiding paraplegia. But we see no reason to expect projection bias to more often mitigate externalities and other errors as opposed to exacerbate them, and we believe that in any event full articulation of all errors and externalities, including projection bias, is the appropriate way to conduct welfare analysis.

Appendix: Proofs

Proof of Lemma 1. To ease our notation, we use $v_t^* \equiv v'(c_t^* - s_t^*)$ for all t. Also, for any function $g(i)$, we say $\Sigma_{i=a}^{b} g(i) = 0$ when $a > b$.

Given $\alpha = 0$, the first-order conditions are $v_t^* - X_t^* = \lambda^*$ for all t, where λ^* is the multiplier on the income constraint, and $X_t^* \equiv \gamma \Sigma_{\tau=t+1}^{T} (1-\gamma)^{\tau-(t+1)} v_\tau^*$. Hence, for all t, $v_{t-1}^* - X_{t-1}^* = v_t^* - X_t^*$ or $v_{t-1}^* - v_t^* = X_{t-1}^* - X_t^*$. Because $X_{t-1}^* - X_t^* = \gamma(v_t^* - X_t^*)$, and because $v_t^* - X_t^* = v_T^*$, it follows that for all t, $v_{t-1}^* - v_t^* = \gamma v_T^* > 0$, which in turn implies $v_t^* = (1 + (T-t)\gamma) v_T^*$. Hence, $v_1^* > \ldots > v_T^*$, which given $v'' < 0$ implies $c_1^* - s_1^* < \ldots < c_T^* - s_T^*$.

For any t, $c_t^* \geq s_t^*$ implies that $c_t^* \geq s_{t+1}^* \geq s_t^*$; combining these conditions with $c_{t+1}^* - s_{t+1}^* > c_t^* - s_t^*$ implies that $c_{t+1}^* > c_t^* \geq s_{t+1}^*$. Hence, if $c_\tau^* \geq s_\tau^*$ for some $\tau < T$, then $c_{\tau+1}^* > c_\tau^* \geq s_{\tau+1}^*$, which in turn implies that $c_{\tau+2}^* > c_{\tau+1}^* \geq s_{\tau+2}^*$, and so forth. The result follows.

Proof of Proposition 1. We use v_t^* as in the proof of Lemma 1, and note that $c_1^* \geq s_1$ implies $c_1^* < \ldots < c_T^*$ and also $c_t^* - s_t^* > 0$ for all $t > 1$. We also use $v_t^A \equiv v'(c_t^A - s_t^A)$ and $\hat{v}_t \equiv v'(c_t^A - s_1)$, and note that $\hat{v}_t > \hat{v}_s$ if and only if $c_t^A < c_s^A$. The first-order conditions are $v_t^A - X_t^A + \alpha/(1-\alpha)\hat{v}_t = \lambda^A/(1-\alpha)$, where λ^A is the multiplier on the income constraint, and $X_t^A \equiv \gamma \Sigma_{\tau=t+1}^{T} (1-\gamma)^{\tau-(t+1)} v_\tau^A$. Hence, for all t, $v_{t-1}^A - v_t^A = X_{t-1}^A - X_t^A + \alpha/(1-\alpha)[\hat{v}_t - \hat{v}_{t-1}]$. Because $X_{t-1}^A - X_t^A = \gamma(v_t^A - X_t^A)$, and because $v_t^A - X_t^A = v_T^A + \alpha/(1-\alpha)[\hat{v}_T - \hat{v}_t]$, it follows that for all t, $v_{t-1}^A - v_t^A = \gamma v_T^A + \alpha/(1-\alpha)[\gamma \hat{v}_T - (\hat{v}_{t-1} - (1-\gamma)\hat{v}_t)]$. By starting with the condition for $t = T$ and iterating backwards, we can derive that for all t,

$$v_t^A = (1 + (T-t)\gamma) v_T^A + \left(\frac{\alpha}{1-\alpha}\right)\left[(1 + (T-t)\gamma)\hat{v}_T - \left(\hat{v}_t + \gamma \sum_{i=t+1}^{T} \hat{v}_i\right)\right].$$

It is useful to rewrite this condition as $v_t^A/(1 + (T-t)\gamma) + \alpha/(1-\alpha) R_t/(1 + (T-t)\gamma) = v_T^A + \alpha/(1-\alpha)\hat{v}_T$, where $R_t = (\hat{v}_t + \gamma \Sigma_{i=t+1}^{\mathrm{T}} \hat{v}_i)$. Also note that for all t and s,

$$(1)\quad \frac{v_t^A - v_t^*}{(1+(T-t)\gamma)} + \frac{\alpha}{1-\alpha}\frac{R_t}{(1+(T-t)\gamma)} = \frac{v_s^A - v_s^*}{(1+(T-s)\gamma)} + \frac{\alpha}{1-\alpha}\frac{R_s}{(1+(T-s)\gamma)}.$$

We next establish two claims.

Claim 1. There exist t and s such that $v_t^A < v_t^*$ and $v_s^A > v_s^*$.

Proof. Suppose otherwise. First, consider the case in which $v_t^A = v_t^*$ for all t, which implies that $c_t^A = c_t^*$ for all t. Applying equation (1), $v_t^A = v_t^*$ for all t implies that $R_t/(1 + (T - t)\gamma) = R_s/(1 + (T - s)\gamma)$ for all t and s; but this requires that $\hat{v}_t = \hat{v}_s$ and therefore $c_t^A = c_s^A$ for all t and s, which contradicts $c_1^* < \ldots < c_T^*$. Next consider the case in which $v_t^A \le v_t^*$ and therefore $c_t^A - s_t^A \ge c_t^* - s_t^*$ for all t, where the inequalities are strict for some t. For any t, if $s_t^A \ge s_t^*$, then $c_t^A - s_t^A \ge c_t^* - s_t^*$ implies that $c_t^A \ge c_t^*$ and therefore $s_{t+1}^A \ge s_{t+1}^*$, where either $s_t^A > s_t^*$ or $c_t^A - s_t^A > c_t^* - s_t^*$ implies that $c_t^A > c_t^*$ and $s_{t+1}^A > s_{t+1}^*$. In addition, $c_1^A - s_1^A \ge c_1^* - s_1^*$ implies that $c_1^A \ge c_1^*$ and therefore $s_2^A \ge s_2^*$, where $c_1^A - s_1^A > c_1^* - s_1^*$ implies that $c_1^A > c_1^*$ and $s_2^A > s_2^*$. It follows that $c_t^A \ge c_t^*$ for all t and $c_t^A > c_t^*$ for some t, which contradicts that $\Sigma_{t=1}^T c_t^A = \Sigma_{t=1}^T c_t^* = Y$. Finally, an analogous logic rules out the case in which $v_t^A \ge v_t^*$ for all t and $v_t^A > v_t^*$ for some t.

Claim 2. There exists $\bar{\tau} \in \{1, \ldots, T - 1\}$ such that $v_t^A \le v_t^*$ for $t \in \{1, \ldots, \bar{\tau}\}$ and $v_t^A > v_t^*$ for $t \in \{\bar{\tau} + 1, \ldots, T\}$.

Proof. Suppose otherwise. Let $x \equiv \max\,\{t | v_t^A \le v_t^*\}$, which exists given Claim 1, and let $z \equiv \max\{t < x | v_t^A > v_t^*\}$, which must exist if the Claim 2 is not true. Applying equation (1), $v_z^A > v_z^*$ and $v_{z+1}^A \le v_{z+1}^*$ together imply that $R_z/(1 + (T - z)\gamma) < R_{z+1}/(1 + (T - z - 1)\gamma)$, which means $[\hat{v}_z + \gamma\hat{v}_{z+1} + \gamma \Sigma_{i=z+2}^T \hat{v}_i]/(1 + (T - z)\gamma) < [\hat{v}_{z+1} + \gamma \Sigma_{i=z+2}^T \hat{v}_i]/(1 + (T - z - 1)\gamma)$ or

$$(2)\quad [1 + (T - z - 1)\gamma]\hat{v}_z - [1 + (T - z - 1)\gamma(1 - \gamma)]\hat{v}_{z+1} < \gamma^2 \sum_{i=z+2}^{T} \hat{v}_i.$$

We prove that inequality (2) cannot hold, from which Claim 2 follows.

We first establish that $c_t^A > c_z^A$ and therefore $\hat{v}_t < \hat{v}_z$ for all

$t \in \{z + 1, \ldots, x\}$. Because $v^*_t > v^*_{t+1}$ for all t, it follows that $v^A_z > v^*_z > v^*_t \geq v^A_t$ for all $t \in \{z + 1, \ldots, x\}$. Since $v^A_t \leq v^*_t$ implies that $c^A_t - s^A_t \geq c^*_t - s^*_t$, $c^*_t - s^*_t > 0$ implies that $c^A_t > s^A_t$ and therefore $s^A_{t+1} > s^A_t$, and so $s^A_t > s^A_{z+1}$ for all $t \in \{z + 2, \ldots, x\}$. If $c^A_z < s^A_z$, then $s^A_{z+1} > c^A_z$, and therefore $c^A_t > s^A_t \geq s^A_{z+1} > c^A_z$. If instead $c^A_z \geq s^A_z$, then $s^A_{z+1} \geq s^A_z$, and since $v^A_z > v^A_t$ implies that $c^A_z - s^A_z < c^A_t - s^A_t$, $s^A_t \geq s^A_{z+1} \geq s^A_z$ implies that $c^A_t > c^A_z$.

If $x = T$, then $\hat{v}_t < \hat{v}_z$ for all $t \in \{z + 2, \ldots, T\}$, and therefore $\gamma^2 \sum_{i=z+2}^{T} \hat{v}_i < \gamma^2(T - z - 1)\hat{v}_z$. But then $\hat{v}_z > \hat{v}_{z+1}$ implies that $\gamma^2(T - z - 1)\hat{v}_z < [1 + (T - z - 1)\gamma]\hat{v}_z - [1 + (T - z - 1)\gamma(1 - \gamma)]\hat{v}_{z+1}$, which contradicts inequality (2).

Consider instead $x < T$. Given $(v^A_t - v^*_t) + \alpha/(1 - \alpha)R_t = (1 - (T - t)\gamma)[v^A_T - v^*_T + \alpha/(1 - \alpha)\hat{v}_T]$, it follows that for all t and s, $1/(s - t)[(v^A_t - v^*_t) - (v^A_s - v^*_s) + \alpha/(1 - \alpha)(R_t - R_s)] = -\gamma[v^A_T - v^*_T + \alpha/(1 - \alpha)\hat{v}_T]$. Hence, $(v^A_z - v^*_z) - (v^A_{z+1} - v^*_{z+1}) + \alpha/(1 - \alpha)(R_z - R_{z+1}) = 1/n[(v^A_x - v^*_x) - (v^A_{x+n} - v^*_{x+n}) + \alpha/(1 - \alpha)(R_x - R_{x+n})]$. Given $v^A_z > v^*_z$, $v^A_{z+1} \leq v^*_{z+1}$, $v^A_x \leq v^*_x$, and $v^A_{x+n} > v^*_{x+n}$, it follows that $(R_x - R_{x+n}) - n(R_z - R_{z+1}) > 0$. Because $R_x - R_{x+n} = \hat{v}_x + \gamma \sum_{i=1}^{n-1} \hat{v}_{x+i} - (1 - \gamma)\hat{v}_{x+n}$ and $R_z - R_{z+1} = \hat{v}_z - (1 - \gamma)\hat{v}_{z+1}$, this condition becomes $(R_x - R_{x+n}) - n(R_z - R_{z+1}) = (1 - \gamma)(\hat{v}_{z+1} - \hat{v}_{x+n}) + [\hat{v}_x + (n - 1)\hat{v}_{z+1} - n\hat{v}_z] + \gamma \sum_{i=1}^{n-1} (\hat{v}_{x+i} - \hat{v}_{z+1}) > 0$. Since $\hat{v}_x < \hat{v}_z$ and $\hat{v}_{z+1} < \hat{v}_z$, applying this condition for $n = 1$ yields $\hat{v}_{z+1} > \hat{v}_{x+1}$, and then applying it for $n = 2$ yields $\hat{v}_{z+1} > \hat{v}_{x+2}$, and so forth. It follows that $\hat{v}_{x+n} < \hat{v}_{z+1} < \hat{v}_z$ for all $n \in \{1, \ldots, T - x\}$, and therefore $\hat{v}_t < \hat{v}_z$ for all $t \in \{z + 1, \ldots, T\}$. But then $\gamma^2 \sum_{i=z+2}^{T} \hat{v}_i < \gamma^2(T - z - 1)\hat{v}_z < [1 + (T - z - 1)\gamma]\hat{v}_z - [1 + (T - z - 1)\gamma(1 - \gamma)]\hat{v}_{z+1}$, which contradicts inequality (2). Claim 2 follows.

Finally, we prove the main result. Posit otherwise, and define $w \equiv \min\{\tau | \sum_{i=1}^{\tau} c^A_i \leq \sum_{i=1}^{\tau} c^*_i\}$. Claims 1 and 2 together imply that $v^A_1 < v^*_1$, and therefore $c^A_1 > c^*_1$. Hence, $w > 1$, and $c^A_w < c^*_w$. Note that if $w \leq \bar{\tau}$ (where $\bar{\tau}$ defined as in Claim 2) then $v^A_1 < v^*_1$, and $v^A_t \leq v^*_t$ for all $t \in \{2, \ldots, w - 1\}$, which implies that $s^A_w > s^*_w$ (using logic identical to that in proof of Claim 1). But then $c^A_w < c^*_w$ implies that $v^A_w > v^*_w$, which contradicts that $w \leq \bar{\tau}$. It follows that $w > \bar{\tau}$ and therefore $v^A_w > v^*_w$.

Define $y \equiv \min\{\tau > w | c^A_\tau \geq c^*_\tau\}$; such a y must exist. We can write the state s_t as

$$s_t = \gamma c_{t-1} + (1-\gamma)\gamma c_{t-2} + (1-\gamma)^2\gamma c_{t-3} + \ldots + (1-\gamma)^{t-2}\gamma c_1 + (1-\gamma)^{t-1}s_1$$
$$= \gamma \sum_{i=1}^{t-1} c_i - \gamma^2 \sum_{j=1}^{t-2}\left[(1-\gamma)^{j-1}\sum_{i=1}^{t-1-j} c_i\right] + (1-\gamma)^{t-1}s_1.$$

Then $\Sigma_{i=1}^{w} c_i^* \geq \Sigma_{i=1}^{w} c_i^A$ and $\Sigma_{i=1}^{\tau} c_i^* < \Sigma_{i=1}^{\tau} c_i^A$ for all $\tau < w$ together imply that

$$s_{w+1}^* - s_{w+1}^A = \gamma\left(\sum_{i=1}^{w} c_i^* - \sum_{i=1}^{w} c_i^A\right) - \gamma^2 \sum_{j=1}^{w-1}\left[(1-\gamma)^{j-1}\left(\sum_{i=1}^{w-j} c_i^* - \sum_{i=1}^{w-j} c_i^A\right)\right] > 0.$$

Moreover, when $y > w+1$, $s_{w+1}^* > s_{w+1}^A$ combined with $c_t^* > c_t^A$ for all $t \in \{w+1, \ldots, y-1\}$ implies that $s_y^* > s_y^A$. Since, by the definition of y, $c_y^A \geq c_y^*$, it follows that $c_y^A - s_y^A > c_y^* - s_y^*$ and therefore $v_y^A < v_y^*$. But given $v_w^A > v_w^*$, this contradicts Claim 2. The result follows.

Proof of Proposition 2. As a preliminary step, we prove $c_1^A < c_3^A$ and $c_2^A < c_3^A$. Posit otherwise, and suppose that $z \in \arg\max_{t\in\{1,2\}} c_t^A$. Hence, $c_z^A \geq c_{z+1}^A$ and $c_z^A \geq c_T^A$, which implies that $\hat{v}_z \leq \hat{v}_{z+1}$ and $\hat{v}_z \leq \hat{v}_T$. Recall that $v_z^A - v_{z-1}^A = \gamma v_T^A + \alpha/(1-\alpha)[\gamma\hat{v}_T - (\hat{v}_z - (1-\gamma)\hat{v}_{z+1})]$. Because $\gamma\hat{v}_T - (\hat{v}_z - (1-\gamma)\hat{v}_{z+1}) = (1-\gamma)(\hat{v}_{z+1} - \hat{v}_z) + \gamma(\hat{v}_T - \hat{v}_z) \geq 0$, $v_z^A - v_{z+1}^A > 0$. Given $v'' < 0$, this implies that $c_z^A - s_z^A < c_{z+1}^A - s_{z+1}^A$, and given $c_z^A \geq c_{z+1}^A$, this holds only if $s_z^A > s_{z+1}^A$, which in turn holds only if $c_z^A < s_z^A$. But if $z = 1$, this contradicts $c_1^A > s_1$, and if $z = 2$, this contradicts $c_2^A > c_1^A > s_2^A$ ($c_1^A > s_1$ implies that $c_1^A > s_2^A$).

In period 1, true utility is $U^1(c_1,c_2,c_3) = \Sigma_{\tau=1}^{3} v(c_\tau - s_\tau)$, and perceived utility is

$$\tilde{U}^1(c_1,c_2,c_3|s_1) = \sum_{\tau=1}^{3} [(1-\alpha)v(c_\tau - s_\tau) + \alpha v(c_\tau - s_1)]$$
$$= (1-\alpha)U^1(c_1,c_2,c_3) + \alpha \sum_{\tau=1}^{3} v(c_\tau - s_1).$$

Period 1 behavior (c_1^A, c_2^A, c_3^A) must satisfy $\partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)/\partial c_1 = \partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)/\partial c_2 = \partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)/\partial c_3$. Because $\partial\tilde{U}^1(c_1, c_2, c_3|s_1)/\partial c_t = (1 - \alpha)\partial U^1(c_1, c_2, c_3)/\partial c_t + \alpha v'(c_t - s_1)$ for $t \in \{1,2,3\}$, $\partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)/\partial c_2 = \partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)/\partial c_3$ implies that $(1 - \alpha)[\partial U^1(c_1^A, c_2^A, c_3^A)/\partial c_2 - \partial U^1(c_1^A, c_2^A, c_3^A)/\partial c_3] = \alpha[v'(c_3^A - s_1) - v'(c_2^A - s_1)]$.

After choosing $c_1^A > s_1$, in period 2, the state is $s_2^A = (1 - \gamma)s_1 + \gamma c_1^A$, true utility is $U^2(c_2, c_3|s_2^A) = \Sigma_{\tau=2}^3 v(c_\tau - s_\tau)$, and perceived utility is $\tilde{U}^2(c_2, c_3|s_2^A) = \Sigma_{\tau=2}^3 [(1 - \alpha)v(c_\tau - s_\tau) + \alpha v(c_\tau - s_2^A)] = (1 - \alpha)U^2(c_2, c_3|s_2^A) + \alpha \Sigma_{\tau=2}^3 v(c_\tau - s_2^A)$. Period 2 behavior (c_2^{AA}, c_3^{AA}) must satisfy $\partial\tilde{U}^2(c_2^{AA}, c_3^{AA}|s_2^A)/\partial c_2 = \partial\tilde{U}^2(c_2^{AA}, c_3^{AA}|s_2^A)/\partial c_3$. Note that for $t \in \{2,3\}$, $\partial U^1(c_1, c_2, c_3)/\partial c_t = \partial U^2(c_2, c_3|s_2^A)/\partial c_t$ for all c_2 and c_3. Hence, because $\partial\tilde{U}^2(c_2, c_3|s_2^A)/\partial c_t = (1 - \alpha)\partial U^1(c_1^A, c_2, c_3)/\partial c_t + \alpha v'(c_t - s_2^A)$ for $t \in \{2,3\}$, $\partial\tilde{U}^2(c_2^A, c_3^A|s_2^A)/\partial c_2 - \partial\tilde{U}^2(c_2^A, c_3^A|s_2^A)/\partial c_3 = \alpha[v'(c_3^A - s_1) - v'(c_2^A - s_1)] + \alpha[v'(c_2^A - s_2^A) - v'(c_3^A - s_2^A)]$.

$v''' > 0$, $s_2^A > s_1$ (which follows from $c_1^A > s_1$), and $c_2^A < c_3^A$ together imply $v'(c_2^A - s_2^A) - v'(c_2^A - s_1) > v'(c_3^A - s_2^A) - v'(c_3^A - s_1)$, which in turn implies that $\partial\tilde{U}^2(c_2^A, c_3^A|s_2)/\partial c_2 > \partial\tilde{U}^2(c_2^A, c_3^A|s_2)/\partial c_3$. Given the concavity of $\tilde{U}^2$, we must have $c_2^{AA} > c_2^A$ and $c_3^{AA} < c_3^A$.

An analogous argument holds for $v''' < 0$.

$v''' = 0$ implies that $v'(c_2^A - s_2^A) - v'(c_2^A - s_1) = v'(c_3^A - s_2^A) - v'(c_3^A - s_1) = k(s_2 - s_1)$ for some constant k (i.e., $v''' = 0$ implies that v' is linear and decreasing, so $-k$ is the slope of v'), and so $\partial\tilde{U}^2(c_2^A, c_3^A|s_2)/\partial c_2 = \partial\tilde{U}^2(c_2^A, c_3^A|s_2)/\partial c_3$. It follows that $(c_2^{AA}, c_3^{AA}) = (c_2^A, c_3^A)$. (The conclusion that $v''' = 0$ yields dynamic consistency would hold for any T and for any c_1^A.)

Proof of Proposition 3. Using the notation from the proof of Proposition 2,

$$\lambda^A = \frac{\partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)}{\partial c_1} = \frac{\partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)}{\partial c_2} = \frac{\partial\tilde{U}^1(c_1^A, c_2^A, c_3^A|s_1)}{\partial c_3},$$

$$\text{and } \lambda^{AA} = \frac{\partial\tilde{U}^2(c_2^{AA}, c_3^{AA}|s_2^A)}{\partial c_2} = \frac{\partial\tilde{U}^2(c_2^{AA}, c_3^{AA}|s_2^A)}{\partial c_3}.$$

The concavity of $\tilde{U}^2$ implies that $\lambda^{AA} \geq \min\{\partial\tilde{U}^2(c_2^A, c_3^A|s_2^A)/\partial c_2, \partial\tilde{U}^2(c_2^A, c_3^A|s_2^A)/\partial c_3\}$. For $t \in \{2,3\}$ we have $\partial\tilde{U}^2(c_2^A, c_3^A|s_2^A)/\partial c_t = \partial\tilde{U}^1(c_1^A,c_2^A,c_3^A|s_1)/\partial c_t + \alpha[v'(c_t^A - s_2^A) - v'(c_t^A - s_1)]$. Then $s_2^A > s_1$ (which follows from $c_1^A > s_1$) combined with $v'' < 0$ implies that $v'(c_t^A - s_2^A) > v'(c_t^A - s_1)$. Hence, for $t \in \{2,3\}$, $\partial\tilde{U}^2(c_2^A, c_3^A|s_2^2)/\partial c_t > \partial\tilde{U}^1(c_1^A,c_2^A,c_3^A|s_1)/\partial c_t = \lambda^A$. The result follows.

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