Time Discounting: A Critical Review

Shane Frederick
Sloan School of Management
Massachusetts Institute of Technology

George Loewenstein
Department of Social and Decision Sciences
Carnegie Mellon University

Ted O'Donoghue
Department of Economics
Cornell University

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Mail: Shane Frederick / Sloan School of Management / MIT / Cambridge, MA 02142; George Loewenstein / Department of Social and Decision Sciences / Carnegie Mellon University / Pittsburgh, PA 15213-3890; Ted O'Donoghue / Department of Economics / Cornell University / 414 Uris Hall / Ithaca, NY 14853-7601. Email: shanefre@mit.edu; GL20@andrew.cmu.edu; and edo1@cornell.edu. Web pages: http://mitsloan.mit.edu/facstaff/; sds.hss.cmu.edu/faculty/loewenstein.html; and www.people.cornell.edu/pages/edo1/.

1. *Introduction*

For more than half a century, economists have analyzed intertemporal-choice behavior using the discounted-utility (DU) model. Although the underlying assumptions of the DU model were never empirically validated, it has been treated as both a normative standard in making public policy — e.g., in cost-benefit analysis — and a descriptively accurate representation of behavior in empirical research. In the last decade, however, there has been a remarkable burst of empirical research on intertemporal choice, much of it addressing the descriptive validity of the DU model. These investigations have uncovered a variety of DU "anomalies" — patterns of choice that are inconsistent with theoretical predictions of the DU model — and, as with the better known anomalies of the expected-utility model, these findings have led economists to propose alternative theoretical models. In this paper, we review the empirical research on intertemporal choice, and present an overview of new theoretical formulations designed to address the shortcomings revealed by this empirical research.

In Section 2, we briefly discuss the historical origins of the DU model. Beginning in the first half of the 19th century, early students of intertemporal choice engaged in a century of exploration into a variety of psychological motives underlying intertemporal choice. When Paul Samuelson proposed the DU model in 1937, all these concerns were condensed into a single parameter, the discount rate. Samuelson's concern was primarily tractability; he expressed manifest reservations about the DU model's normative and descriptive validity.

In Section 3, we describe some important features of the DU model as it is commonly used by economists, highlighting those features which illustrate the implicit psychological assumptions underlying the model. In Section 4, we discuss the recent empirical research which documents a variety of DU anomalies. In Section 5, we review alternative theoretical models that have been proposed in light of these anomalies. Some of these models modify the discount function, permitting, for example, declining discount rates or "hyperbolic discounting." Others introduce additional arguments into the utility function, such as habit formation, reference-dependent utility, and anticipatory utility. Still others posit more extreme departures from the DU model, suggesting, for instance, that people mispredict future utility. These new theories have revived many of the psychological considerations discussed prior to the advent of the DU model.

In Section 6, we review the numerous empirical studies over the past 30 years which have

attempted to estimate discount rates. While the DU model assumes that people are characterized by a single discount rate, this literature has failed to identify any robust estimates of discount rates across studies (and sometimes even within studies). This failure is partly due to invalid assumptions — e.g., that choices are made in isolation, that utility is linear in amount, or that people are certain about the receipt of future rewards. But it is also attributable to the fact that there are many motives behind intertemporal choices, and empirical studies which measure discount rates assume, incorrectly, that all these motives can be condensed into a single discount rate.

Our discussion in Sections 5 and 6 suggests distinguishing a variety of motives as distinct from time preference, such as uncertainty or habit formation or utility from anticipation. In Section 7, we discuss the usefulness of unpacking time preference itself into more basic subcomponent motives. Section 8 concludes.

2. *Historical Origins of the Discounted Utility Model*

The historical developments which culminated in the formulation of the DU model help to explain the model's limitations. Each of the major figures in the development of the DU model — John Rae, Eugen von Böhm-Bawerk, Irving Fisher, and Paul Samuelson — built upon the theoretical framework of his predecessors drawing on little more than introspection and personal observation. When the DU model eventually became entrenched as the dominant theoretical framework for modeling intertemporal choice, it was due largely to its simplicity and its resemblance to the familiar compound interest formula, and not as a result of empirical research that demonstrated its validity.

Intertemporal choice became firmly established as a distinct topic in 1834, with John Rae's publication of the Sociological Theory of Capital. Like his better known contemporary, Adam Smith, Rae sought to determine why wealth differed between nations. Smith had argued that national wealth was determined by the amount of labor allocated to the production of capital, but Rae recognized that this account was incomplete because it failed to explain the determinants of this allocation. The missing element, Rae argued, was the psychological factor — "the effective desire of accumulation" — which Rae believed differed across countries and determined the

amount of saving and investment in a society. Rae not only "invented" the topic of intertemporal choice, but also produced the first in-depth discussion of the psychological motives underlying time preference.

Rae described four factors that influence the effective desire of accumulation, two of which limit it, and two which promote it. One of the limiting factors was the uncertainty of human life:

> When engaged in safe occupations, and living in healthy countries, men are much more apt to be frugal, than in unhealthy, or hazardous occupations, and in climates pernicious to human life. Sailors and soldiers are prodigals. In the West Indies, New Orleans, the East Indies, the expenditure of the inhabitants is profuse. The same people, coming to reside in the healthy parts of Europe, and not getting into the vortex of extravagant fashion, live economically. War and pestilence have always waste and luxury, among the other evils that follow in their train. (Rae 1834:57)

A second limiting factor was the excitement produced by the prospect of immediate consumption, and the concomitant discomfort of deferring such available gratifications:

> Such pleasures as may now be enjoyed generally awaken a passion strongly prompting to the partaking of them. The actual presence of the immediate object of desire in the mind by exciting the attention, seems to rouse all the faculties, as it were to fix their view on it, and leads them to a very lively conception of the enjoyments which it offers to their instant possession. (Rae 1834:120)

The two factors thought to promote the effective desire of accumulation were "the prevalence throughout the society of the social and benevolent affections" (page 58), which is closely related to the bequest motive, and the propensity to exercise self restraint — "the extent of the intellectual powers, and the consequent prevalence of habits of reflection, and prudence, in the minds of the members of society" (page 58).

In Rae's four factors influencing the effective desire for accumulation, one can glimpse two fundamentally different views. One, which was later championed by William S. Jevons

(1888) and his son, Herbert S. Jevons (1905), assumed that people cared only about their immediate utility. This view explained farsighted behavior by the observation that people derive immediate utility not only from immediate consumption, but also from the anticipation of future consumption. Deferral of gratification would occur only if it produced an increase in "anticipal" utility that more than compensated for the decrease in immediate consumption utility.

The second perspective assumed equal treatment of present and future (zero discounting) as the natural baseline for behavior, and attributed the overweighting of the present to the miseries produced by the self-denial required to delay gratification. As N.W. Senior, the best-known advocate this "abstinence" perspective, wrote, "To abstain from the enjoyment which is in our power, or to seek distant rather than immediate results, are among the most painful exertions of the human will" (Senior 1836:60).

The anticipatory-utility and abstinence perspectives shared the idea that intertemporal tradeoffs depend on immediate feelings — the immediate pleasure of anticipation, or the immediate discomfort of self-denial. However, the two perspectives explained variability in intertemporal choice behavior in different ways. The anticipatory-utility perspective focused on individual differences in the ability to imagine the future and in the vividness with which different future outcomes can be imagined. The abstinence perspective, on the other hand, emphasized individual differences in factors that affect the psychological discomfort of self-denial, such as vulnerability to frustration and the ability of objects to elicit frustration.

Eugen von Böhm-Bawerk, the next major figure in the development of the economic perspective on intertemporal choice, added a new motive to those proposed by Rae, Jevons, and Senior, arguing that humans suffer from a systematic tendency to underestimate future wants:

> It may be that we possess inadequate power to imagine and to abstract, or that we are not willing to put forth the necessary effort, but in any event we limn a more or less incomplete picture of our future wants and especially of the remotely distant ones. And then there are all those wants that never come to mind at all (Böhm-Bawerk 1889:268-269).[1]

[1]In a frequently cited passage from Economics of Welfare, Arthur Pigou (1920) proposed a similar account of time discounting, suggesting that there is a type of cognitive illusion: “our telescopic faculty is defective, and we, therefore, see future pleasures, as it were, on a diminished scale.”

Böhm Bawerk's analysis of time preference, like those of his predecessors, was heavily psychological, and much of his voluminous treatise, Capital and Interest, was devoted to discussions of the psychological constituents of time preference. However, whereas the early views of Rae, Senior, and Jevons explained intertemporal choices in terms of motives that are uniquely associated with time, Böhm Bawerk began modeling intertemporal choice in the same terms as other economic tradeoffs — as a "technical" decision about allocating resources (to oneself) over different points in time, much as one would allocate resources between any two competing interests, such as housing and food.

Böhm Bawerk's treatment of intertemporal choice as an allocation of consumption between time periods was formalized a decade later by the American economist, Irving Fisher (1930). Fisher plotted the intertemporal consumption decision on a two-good indifference diagram, with consumption in the current year on the abscissa, and consumption in the following year on the ordinate. This representation made clear that a person's observed (marginal) rate of time preference — the marginal rate of substitution at her chosen consumption bundle — depends on two considerations: time preference and considerations of diminishing marginal utility. Many economists have subsequently expressed discomfort with using the term "time preference" to include the effects of differential marginal utility arising from unequal consumption levels between time periods. For example, Mancur Olson and Martin Bailey (1981, p. 5): "strongly suggest that 'positive time preference' be defined to exclude the effect of a difference in marginal utility due to any lower level of consumption in the present and, therefore, to include only preferences for present over future consumption due to other causes." In Fisher's formulation, *pure* time preference can be interpreted as the marginal rate of substitution on the diagonal (where consumption is equal in both periods).

Fisher's writings, like that of his predecessors, included extensive discussions of the psychological determinants of time preference. Like Böhm-Bawerk, he differentiated "objective factors," such as projected future wealth and risk, from "personal factors." Fisher's list of personal factors included the four factors described by Rae, "foresight" (the inverse of Böhm-Bawerk's "systematic tendency to underestimate future wants"), and a new influence called "fashion" which Fisher believed to be "of vast importance ... in its influence both on the rate of interest and on the distribution of wealth itself" (Fisher 1930:88):

> The most fitful of the causes at work is probably fashion. This at the present time acts, on the one hand, to stimulate men to save and become millionaires, and, on the other hand, to stimulate millionaires to live in an ostentatious manner. (Fisher 1930:87)

Hence, in the early part of the 20th century, "time preference" was viewed as an amalgamation of a variety of intertemporal motives. Table 1 summarizes the various psychological motives described above.

(Table 1 here)

3. *The Discounted Utility Model*

In 1937, Paul Samuelson introduced the DU model in a five page article titled "A Note on Measurement of Utility." Samuelson's primary concern was tractability. Fisher's graphical indifference-curve analysis was difficult to extend to more than two time periods. Furthermore, tradeoffs between utility at different points in time necessitate a cardinal measure of utility, which was a central point of Samuelson's paper. But in Samuelson's simplified model, all the psychological concerns discussed over the previous century were condensed into a single parameter, the discount rate.

The DU model specifies a decision maker's intertemporal preferences over consumption profiles $(c_t,...,c_T)$. Under the usual assumptions (completeness, transitivity, and continuity), such preferences can be represented by an intertemporal utility function $U^t(c_t,...,c_T)$. The DU model goes further, assuming that a person's intertemporal utility function can be described by the following special functional form:

$$U^t(c_t,...,c_T) = \sum_{k=0}^{T-t} D(k)\, u(c_{t+k}) \qquad \text{where } D(k) = \left(\tfrac{1}{1+r}\right)^k .$$

In this formulation, $u(c_{t+k})$ is often interpreted as the person's cardinal instantaneous utility function — her well-being in period $t+k$ — and $D(k)$ is often interpreted as the person's discount function — the relative weight she attaches, at time t, to her well-being in period $t+k$.
ρ represents the individual's pure rate of time preference (her discount rate), which is meant to

reflect the collective effects of the "psychological" motives discussed in Section 2.[2]

Samuelson did not endorse the DU model as a normative model of intertemporal choice, noting that "any connection between utility as discussed here and any welfare concept is disavowed" (p. 161). He also made no claims on behalf of its descriptive validity, stressing "It is completely arbitrary to assume that the individual behaves so as to maximize an integral of the form envisaged in [the DU model]" (p. 159). However, despite Samuelson's manifest reservations, the simplicity and elegance of this formulation was irresistible, and the DU model was rapidly adopted as the framework of choice for analyzing intertemporal decisions.

The DU model received a scarcely needed further boost to its dominance as the standard model of intertemporal choice in 1960 when Tjalling C. Koopmans (1960) showed that the model could be derived from a superficially plausible set of axioms about properties of choice. As was true of Samuelson's paper (1937) , however, Koopmans' goal was not to argue that the DU model was psychologically or normatively plausible. In Koopmans' case it was to show that, under some well-specified (though arguably unrealistic) circumstances, individuals were logically compelled to possess positive time preference. Producers of a product cannot, however, dictate how the product will be used, and Koopmans' central technical message was largely lost while his axiomatization of the DU model helped to cement its popularity and bolster its perceived legitimacy.

In the remainder of this section, we describe some important features of the DU model as it is commonly used by economists, and briefly comment on the normative and positive validity of these assumptions. These features do not represent an axiom system — they are neither necessary nor sufficient conditions for the DU model — but are intended to illustrate the implicit psychological assumptions underlying the model.[3]

3.1 *Integration of new alternatives with existing plans*

A central assumption in most models of intertemporal choice — including the DU model

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[2]The continuous-time analogue is $U^t(\{c_t\}_{t\in[t,T]}) = \int_{t=t}^{T} e^{-r(t-t)}u(c_t)$. For expositional ease, we shall restrict attention to discrete-time throughout.

[3]There are several different axiom systems for the DU model — in addition to Koopmans, see Peter Fishburn (1970), K.J. Lancaster (1963), Richard F. Meyer (1976) and Fishburn and Ariel Rubinstein (1982).

— is that a person evaluates new alternatives by integrating them with her existing plans. To illustrate, consider a person with existing consumption plan $(c_t,...,c_T)$ who is offered an intertemporal-choice prospect X, which might be something like an option to give up $5000 today to receive $10,000 in five years. Integration means that prospect X is not evaluated in isolation, but in light of how it changes the person's aggregate consumption in all future periods. That is, to evaluate the prospect X, the person must calculate what her new optimal consumption path $(c'_t,...,c'_T)$ would be if she were to accept prospect X, and should accept the prospect only if $U^t(c'_t,...,c'_T) \geq U^t(c_t,...,c_T)$.

An alternative way to understand integration is to recognize that intertemporal prospects alter a person's budget set. If the person's initial endowment is E_0, then accepting prospect X would change her endowment to $\mathrm{E}_0 \cup X$. Letting $\mathrm{B(E)}$ denote the person's budget set given endowment E — i.e., the set of consumption streams that are feasible given endowment E — the DU model says that the person should accept prospect X if

$$\max_{(c_t,...,c_T)\in \mathrm{B}(\mathrm{E}_0 \cup X)} \sum_{t=t}^{T} \left(\tfrac{1}{1+r}\right)^{t-t} u(c_t) \quad > \quad \max_{(c_t,...,c_T)\in \mathrm{B}(\mathrm{E}_0)} \sum_{t=t}^{T} \left(\tfrac{1}{1+r}\right)^{t-t} u(c_t).$$

While integration seems normatively compelling, it may be too difficult to actually do. One may not have well formed plans about future consumption streams, or be unable (or unwilling) to recompute the new optimal plan every time one makes an intertemporal choice. Some of the evidence we review below supports the plausible presumption that people evaluate the results of intertemporal choices largely independently of the expectations they have for consumption in the relevant future time periods.

3.2 Utility Independence

The DU model explicitly assumes that the overall value — or "global utility" — of a sequence of outcomes is equal to the (discounted) sum of the utilities in each period. Hence, the distribution of *utility* across time makes no difference beyond that dictated by discounting, which (assuming positive time preference) penalizes utility that is experienced later. The assumption of utility independence has rarely been discussed or challenged, but its implications are far from innocuous. It rules out any kind of special preference for patterns of utility over time — e.g., a preference for an increasing utility profile or a preference for a "flat" utility profile over a "roller-

coaster" profile or vice versa.[4]

3.3 Consumption Independence

The DU model explicitly assumes that a person's well-being in period $t+k$ is independent of her consumption in any other period, or equivalently that the marginal rate of substitution between consumption in periods t and t' is independent of consumption in period t''.

Consumption independence is analogous to, but fundamentally different from, the independence axiom of expected-utility theory. In expected-utility theory, the independence axiom says that preferences over uncertain prospects are not affected by the consequences that the prospects share, or equivalently that the utility of an experienced outcome is unaffected by other outcomes that one might have experienced (but did not). In intertemporal choice, consumption independence implies that preferences over consumption profiles are not affected by the periods in which consumption is the same across profiles, or equivalently that the utility of an experienced outcome is unaffected by outcomes experienced in prior or future periods. For example, consumption independence says that a person's preference for an Italian vs. Thai restaurant dinner tomorrow night should be independent of whether she has Italian or Thai tonight or expects to eat Italian or Thai the night after tomorrow. As the example suggests, and as even Samuelson and Koopmans recognized, there is no good reason to assume that consumption independence holds. Samuelson (1952:674) noted that, "the amount of wine I drank yesterday and will drink tomorrow can be expected to have effects upon my today's indifference slope between wine and milk." Similarly, Koopmans (1960, p. 292) acknowledged that, "One cannot claim a high degree of realism for [the independence assumption], because there is no clear reason why complementarity of goods could not extend over more than one time period."

3.4 Stationary Instantaneous Utility

In applications of the DU model to specific problems, it is often assumed that the cardinal instantaneous utility function $u(c_t)$ is constant across time, so that the well-being generated by

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[4] Of course, "utility independence" has meaning only if one literally interprets $u(c_{t+k})$ as well-being experienced in period $t+k$. We believe that this is, in fact, the common interpretation. For a model that relaxes this assumption, see Benjamin Hermalin and Alice Isen (2000), who consider an abstract model in which well-being in period t depends on well-being in period $t-1$ — i.e., they assume $u_t = u(c_t, u_{t-1})$.

any activity is the same in different periods. Most economists would acknowledge that stationarity of the instantaneous utility function is not sensible in many situations, because people's preferences do in fact change over time both from lifecycle changes (i.e., maturation), and from random fluctuations.[5] The assumption is often adopted, however, for the sake of analytical convenience. As economists gain insight into how tastes change over time, this simplification becomes less defensible.

3.5 Independence of discounting from consumption

The DU model assumes that the discount function used for intertemporal-choice decisions is invariant across all forms of consumption. This feature of the DU model is crucial to the notion of *time* preference. If people discount utility from different sources at different rates, then the notion of a unitary time preference is meaningless. Instead we would need to label time preference according to the object being delayed — "banana time preference," "vacation time preference," etc. We discuss the validity of this assumption in more detail in Section 7.

3.6 Constant Discounting and Time Consistency

Any discount function can be written in the form $D(k) = \prod_{n=0}^{k-1}\left(\frac{1}{1+r_n}\right)$, where r_n represents the per-period discount rate for period n — that is, the discount rate applied between periods n and $n+1$. Hence, by assuming that the discount function takes the form $D(k) = \left(\frac{1}{1+r}\right)^k$, the DU model assumes a constant per-period discount rate ($r_n = r$ for all n).[6]

Constant discounting represents an even-handedness in the way a person deals with time. If a person prefers a plebeian beach holiday today over a luxurious vacation in a month, constant discounting implies that, deciding now, she should prefer the plebeian holiday in a year over the luxurious vacation in a year and a month. Constant discounting represents a useful simplification

[5] As we discuss in Section 5, endogenous preference changes, due to things such as habit formation or reference dependence, are best understood in terms of consumption interdependence and not non-stationary utility. In some situations, non-stationarities clearly play an important role in behavior — e.g., Steven Suranovic, Robert Goldfarb, and Thomas Leonard (1999) and Ted O'Donoghue and Mathew Rabin (1999a;2000) discuss the importance of non-stationarities in the realm of addictive behavior.

[6] An alternative but equivalent way to define constant discounting is $D(k)/D(k+1)$ is independent of k.

for analyzing a person's time preference, because time preference can be summarized by a single "discount rate."

An important implication of constant discounting is that a person's intertemporal preferences are *time-consistent*, which means that later preferences "confirm" earlier preferences. Formally, a person's preferences are time-consistent if for any consumption profiles $(c_t,...,c_T)$ and $(c'_t,...,c'_T)$ with $c_t = c'_t$, $U^t(c_t, c_{t+1},...,c_T) \geq U^t(c'_t, c'_{t+1},...,c'_T)$ if and only if $U^{t+1}(c_{t+1},...,c_T) \geq U^{t+1}(c'_{t+1},...,c'_T)$.[7] For an interesting discussion on the normative validity of constant discounting, see Martin Albrecht and Martin Weber (1995).

3.7 Diminishing marginal utility and positive time preference

While not core features of the DU model, virtually all analyses of intertemporal choice assume diminishing marginal utility — that the instantaneous utility function $u(c_t)$ is concave — and positive time preference — that the discount rate ρ is positive. These two assumptions constitute opposing forces in intertemporal choice: diminishing marginal utility motivates a person to spread consumption over time, while positive time preference motivates a person to accelerate consumption towards the present.

Since people do, in fact, spread consumption over time, the assumption of diminishing marginal utility (or some other property that has the same effect) seems strongly justified. The assumption of positive time preference, on the other hand, is more questionable. Several researchers have argued for positive time preference on logical grounds (Jack Hirshleifer 1970; Koopmans 1960; Koopmans, Peter A. Diamond, and Richard E. Williamson 1964; Olson and Bailey 1981). The gist of their arguments is that a zero or negative time preference, combined with a positive real rate of return on saving, would command the infinite deferral of all consumption. In the context of intergenerational choice, Koopmans (1967) called this result the *paradox of the indefinitely postponed splurge*. (See also Kenneth J. Arrow 1983; S. Chakravarty 1962; Robert M. Solow 1974). But this conclusion rests on a number of restrictive and absurdly

[7]Constant discounting implies time-consistent preferences only under the quite reasonable ancillary assumption of stationary discounting, which says that the discount function *D(k)* is the same in all periods. As a counter-example, if the period-*t* discount function is $D_t(k) = \left(\frac{1}{1+r}\right)^k$ while the period-*t+1* discount function is $D_{t+1}(k) = \left(\frac{1}{1+r'}\right)^k$ for some $r' \neq r$, then the person exhibits constant discounting at both dates *t* and *t+1*, but she nonetheless has time-inconsistent preferences.

unrealistic assumptions, including infinitely lived agents and linearity (or weak concavity) of the utility function. Nevertheless, in econometric analyses of savings and intertemporal substitution, positive time preference is sometimes treated as an identifying restriction whose violation is interpreted as evidence of mis-specification.[8]

The most compelling argument supporting the logic of positive discounting was made by Derek Parfit (1971;1976;1982), who contends that there is no enduring self or "I" over time to which all future utility can be ascribed, and that a diminution in psychological connections gives our descendent future selves the status of other people — making that utility less than fully "ours" and giving us a reason to count it less:

> We care less about our further future ... because we know that less of what we are now — less, say, of our present hopes or plans, loves or ideals — will survive into the further future ... [if] what matters holds to a lesser degree, it cannot be irrational to care less. (Parfit 1971:99).

Parfit's claims are normative, not descriptive. He is not attempting to explain or predict people's intertemporal choices, but is arguing that conclusions about the rationality of discounting must be grounded on a correct view of personal identity. Parfit's position is that identity could plausibly diminish over time, and that this permits some degree of discounting (see Shane Frederick 1999 for an expanded discussion).[9] Frederick (1999) examines whether Parfit's position holds at a descriptive level. He found no relation between monetary discount rates (as imputed from procedures such as "I would be indifferent between $100 tomorrow and $_____ in 5 years") and self perceived stability of identity (e.g., "Compared to now, how similar were you 5 years ago

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[8] Positive time preference is also sometimes interpreted as a modeling simplification that captures the effects of unmodeled uncertainty.

[9] As noted by Frederick (1999), there is much disagreement about the nature of Parfit's claim. In her review of the philosophical literature, J. Whiting (1986, p. 549) identifies four different interpretations: (1) the *strong absolute claim* that it is irrational for someone to care about their future welfare, (2) the *weak absolute claim* that there is no rational requirement to care about one's future welfare, (3) the *strong comparative claim* that it is irrational to care more about one's own future welfare than about the welfare of any other person, and (4) the *weak comparative claim* that one is not rationally required to care more about their future welfare than about the welfare of any other person. We believe that all of these interpretations are too strong, and that Parfit endorses only a weaker version of the weak absolute claim. That is, he claims only that one is not rationally required to care about one's future welfare to a degree which exceeds the degree of psychological connectedness that obtains between one's current self and one's future self.

[will you be 5 years from now]?). Nor did he find any relation between monetary discount rates and the presumed correlates of identity stability (e.g., the extent to which people agree with the statement "I am still embarrassed by stupid things I did a long time ago."). Thus the only study conducted so far that examines the issue finds no support for the idea that an individual's philosophical views on the temporal stability of self can help to explain interpersonal variability in intertemporal behaviors.

4. *DU Anomalies*

Over the last two decades, empirical research on intertemporal choice has documented various inadequacies of the DU model as a descriptive model of behavior. Discount rates are not constant over time, but appear to decline, a pattern often referred to as "hyperbolic time discounting." Moreover, different types of intertemporal choices — e.g., those involving gains vs. those involving losses — reveal radically different degrees of discounting.

It will be useful for our discussion to distinguish *discounting* from *time preference*. We will use the term *discounting* broadly to encompass *any* reason for caring less about a future consequence, including factors that affect the utility generated by a future consequence, such as uncertainty or utility-function curvature. We will use the term *time preference* to refer to the preference for immediate *utility* over delayed *utility*.[10]

4.1 *Hyperbolic discounting*

The best documented DU anomaly is declining discount rates (in our notation, r_n is declining in *n*), which is often referred to as hyperbolic discounting. Direct evidence of declining discount rates comes from a large experimental literature in psychology and behavioral economics

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[10] John Broome (1995, p. 128-129) notes that some of the controversy about discounting results from differences in how the term is used: "*On the face of it ... typical economists and typical philosophers seem to disagree. But actually I think there is more misunderstanding here than disagreement ... When economists and philosophers think of discounting, they typically think of discounting different things. Economists typically discount the sorts of goods that are bought and sold in markets* [whereas] *philosophers are typically thinking of a more fundamental good, people's well-being ... It is perfectly consistent to discount commodities and not well-being.*"

that has attempted to identify precisely the discount function that people use for intertemporal choices. In such studies, subjects are typically asked to compare a smaller-sooner reward to a larger-later reward using either choice tasks or matching tasks (see Section 6 for a description of these procedures).

A prevalent finding in this literature is that the average discount rate over longer intervals is lower than the average discount rate over shorter intervals. For example, Richard Thaler (1981) asked subjects to specify the amount of money they would require in [one month / one year / ten years] to make them indifferent to receiving $15 now. The median responses [$20 / $50 / $100] imply an average (annual) discount rate of 345% over a one-month horizon, 120% over a one-year horizon, and 19% over a ten-year horizon.[11] This pattern has been found in a number of studies (Uri Ben-Zion, Amnon Rapoport, and Joseph Yagil 1989; Gretchen B. Chapman 1996; Chapman and Arthur S. Elstein 1995; John L. Pender 1996; Daniel A. Redelmeier and Daniel N. Heller 1993). In addition, this pattern shows up *across studies*. Using the studies we summarize in Section 6 (which are described in more detail in Table 2 in Section 6), Figure 1 plots the estimated discount rate for each study against time horizon for that study.[12] As the fitted curve reflects, the estimated discount factor (equal to 1/(1+discount rate)) increases with the time horizon.

(insert Figure 1 here)

Some researchers have attempted to explicitly fit mathematical functions to such data. Specifically, they have pitted exponential time-discount functions, which impose constant discount rates, against hyperbolic time-discount functions, which impose declining discount rates.[13]

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[11] That is, $15 = $20*($e^{-(3.45)(1/12)}$) = $50*($e^{-(1.20)(1)}$) = $100*($e^{-(0.19)(10)}$). While most empirical studies report average discount rates over a given horizon, it is sometimes more useful — especially for making comparisons to our theoretical framework — to discuss average "per-period" discount rates. Framed in these terms, Thaler's results imply an average (annual) discount rate of 345% between now and one month from now, 100% between one month from now and one year from now, and 7.7% between one year from now and ten years from now. That is, $15 = $20*($e^{-(3.45)(1/12)}$) = $50*($e^{-(3.45)(1/12)}$ $e^{-(1.00)(11/12)}$) = $100*($e^{-(3.45)(1/12)}$ $e^{-(1.00)(11/12)}$ $e^{-(0.077)(9)}$).

[12] In some cases, the discount rates were computed from the median respondent. In other cases, the mean discount rate was used.

[13] Several hyperbolic functional forms have been proposed: George Ainslie (1975) suggested the function $D(t) = 1/t$, Richard Herrnstein (1981) and James Mazur (1987) suggested $D(t) = 1/(1+at)$, and George

Virtually every such study has found that the hyperbolic functional form statistically fits the data better than the exponential functional form (Kris N. Kirby 1997; Kirby and Nino Marakovic 1995; Joel Myerson and Leonard Green 1995; Howard Rachlin, Andres Raineri, and David Cross 1991).

A second line of evidence for hyperbolic discounting are demonstrations of preference reversals. Preference reversals are said to occur when a subject prefers an immediate smaller reward over a delayed larger reward, but prefers the delayed larger reward when a constant delay is added to both options (e.g., a person prefers $100 now to $110 tomorrow, while at the same time she prefers $110 in 31 days to $100 in 30 days). Such intertemporal preference reversals have been found in humans (Green, Nathanael Fristoe, and Myerson 1994; Kirby and Herrnstein 1995; Andrew Millar and Douglas Navarick 1984; Jay Solnick, Catherine Kannenberg, David Eckerman, and Marcus Waller 1980) and in pigeons (Ainslie and Herrnstein 1981; Green, E.B. Fischer, Jr., Steven Perlow, and Lisa Sherman 1981).

A third line of evidence for hyperbolic discounting are demonstrations of a preference for commitment — evidence of people choosing to constrain their future choices. A person who currently prefers, say, $110 in 11 weeks over $100 in 10 weeks, but who knows that in 10 weeks she will prefer $100 immediately to $110 one week later, might attempt to eliminate the $100 reward from the later choice set, thereby binding herself *now* to receive the $110 reward in 11 weeks. There are many real world examples in which people take steps to constrain their future choices, such as joining "Christmas clubs" or "fat farms." A natural interpretation of many such examples is that people are attempting to ensure that they receive the larger-later reward (e.g., sufficient funds for Christmas presents or losing weight) rather than a smaller-sooner reward (e.g., short-term consumption or ice cream), which might otherwise occur if their preferences reversed when the smaller rewards became imminent.

One of the best empirical studies of a preference for commitment was conducted by Dan Ariely and Klaus Wertenbroch (in press). In one study, MIT executive-education students who had to write three short papers for a class were assigned to one of two experimental conditions. In one condition, each student was allowed to set her own deadlines for each of the three papers, with the understanding that she would receive a 1% penalty for each day the paper was "late" relative to her self-imposed deadlines. A second group of students had deadlines imposed on them that were evenly spaced across the semester, with the same 1% penalty for lateness.

Loewenstein and Drazen Prelec (1992) suggested $D(t) = 1/(1+at)^{b/a}$.

Although students in the former condition could have made all three papers due at the end of the semester, many chose to impose deadlines on themselves, which suggests that they saw value to commitment. Moreover, students who did not impose deadlines on themselves handed in their papers later in the semester, and performed worse than students with self-imposed deadlines and those who had deadlines imposed on them. This result further illustrates the value of commitment, and suggests that some students did not fully appreciate this value.[14]

While preference reversals and a preference for commitment are *consistent* with declining discount rates, such indirect evidence is perhaps less than convincing because they are also consistent with several other phenomena. For instance, in Section 5, we discuss how anticipatory utility might lead to time-inconsistent preferences and therefore a preference for commitment (as suggested by Andrew Caplin and John Leahy 2001; Loewenstein 1987). We also discuss how preference reversals and a preference for commitment can be generated by emotions and other "visceral factors" (as suggested by Loewenstein 1996) and by "temptation preferences" wherein people experience disutility from not pursuing the most immediately enjoyable action (as suggested by Faruk Gul and Wolfgang Pesendorfer 2001, and much earlier by N.W. Senior).

Adding to these doubts about the robustness of the evidence supporting declining discount rates, a recent study by Daniel Read (2000) casts doubt on the direct evidence of declining discount rates. As noted above, hyperbolic discounting is often inferred from the common finding that implicit discount rates over longer intervals are lower than implicit discount rates over shorter intervals. Read points out, however, that "subadditive discounting" would generate the same pattern. Subadditive discounting means that the total amount of discounting over a temporal interval is larger the more finely that interval is subdivided. For instance, if one were to elicit (annual) discount rates for now vs. one year (r_{01}), one year vs. two years (r_{12}), and now vs. two years (r_{02}), subadditivity implies $(1+r_{02})^2 < (1+r_{01})(1+r_{12})$. Read's proposal that discounting is subadditive is compatible with analogous results in other domains. For example, Amos Tversky and Derek Koehler (1994) found that the total probability assigned to an event increases the more finely the event is partitioned — e.g., the probability of "death by accident" is judged to be more

[14] A similar "natural" experiment was recently conducted by the Economic and Social Research Council of Great Britain. They recently eliminated submission deadlines and now accept grant proposals on a "rolling" basis (though they are still reviewed only periodically). In response to this policy change, submissions have actually declined by about 15-20% (direct correspondence with Chris Caswill at ESRC).

likely if one separately elicits the probability of "death by electrocution," "death by drowning," "death by falling," etc.

Read designed an experiment to empirically unconfound declining discount rates from subadditive discounting. In one study, he elicited discount rates for a two-year (24-month) interval and for its three constituent intervals, an eight-month interval beginning at the same time, an eight-month interval beginning eight months later, and an eight-month interval beginning in 16 months later. The average discount rate for the 24-month interval was lower than the compounded average discount rate over the three eight-month subintervals — a result predicted by subadditive discounting but inconsistent with hyperbolic discounting (and also exponential discounting). Moreover, there was no evidence of declining discount rates, as the discount rates for the three eight-month intervals were approximately equal. In fact, J.H. Holcomb and P.S. Nelson (1992) had earlier found similar empirical results, although they did not interpret their results in this fashion. Notice that the evidence in Read (2000) and in Holcomb and Nelson (1992) stand in stark contrast to the literature on preference reversals. Thus far, it is unclear why some studies reveal "preference reversals," but others do not.[15]

4.2 *Other DU anomalies*

The DU model not only dictates that the discount rate should be constant for all time periods, it assumes that the discount rate should be the same for all types of goods and all categories of intertemporal decisions. However, there are several empirical regularities that appear to contradict this assumption, namely: (1) gains are discounted more than losses; (2) small amounts are discounted more than large amounts; (3) greater discounting is shown to avoid delay of a good than to expedite its receipt; (4) in choices over sequences of outcomes, improving sequences are often preferred to declining sequences, though positive time preference dictates the

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[15] Rubinstein (2000) also provides examples in which subjects behave in a way that is inconsistent with both hyperbolic and exponential discounting; but it seems likely that his results are driven by framing, bracketing (see Section 5), or display effects. Several other empirical results are also inconsistent with hyperbolic discounting. Frederick (1999) asked 228 respondents to imagine that they worked at a job that consisted of both pleasant work ("good days") and unpleasant work ("bad days") and to equate the attractiveness of having additional good days this year or in a future year. On average, respondents were indifferent between getting 20 extra good days this year or 21 the following year or 40 in five years. This implies a one year discount rate of 5% that is much lower than the average five-year discount rate of 15%. Frederick and Loewenstein (2000) found that respondents who expected to receive $1000 gift certificate in one year would pay more to advance its receipt from 12 months to 10 months than to advance it from 10 months to 8 months, though declining discount rates (indeed, even constant discount rates) predict the opposite.

opposite; and (5) in choices over sequences, violations of independence are pervasive, and people seem to have a preference for spreading utility over time (in a fashion not well explained by simple diminishing marginal utility).

4.2.1 *The "sign effect" (gains are discounted more than losses)*

A number of studies have concluded that gains are discounted at a higher rate than losses. For instance, Thaler (1981) asked subjects to imagine they had received a traffic ticket and to state how much extra they would be willing to pay if they could delay payment by 3 months, 1 year, or 3 years. The discount rates imputed from these answers were much lower than the discount rates imputed from comparable questions about monetary gains (which we discussed earlier). This pattern is prevalent in the literature. Indeed, in many studies, a substantial proportion of subjects prefer to incur a fixed loss immediately rather than delay it (Ben-Zion, Rapoport, and Yagil 1989; L. D. MacKeigan, L. N. Larson, J. R. Draugalis, J. L. Bootman, and L. R. Burns 1993; Walter Mischel, Joan Grusec, and John C. Masters 1969; Redelmeier and Heller 1993; J. Frank Yates and Royce A. Watts 1975).

4.2.2 *The "magnitude effect" (small outcomes are discounted more than large ones)*

Most studies that vary outcome size have found that small outcomes are discounted at a higher rate than large ones (Ainslie and Varda Haendel 1983; Ben-Zion, Rapoport, and Yagil 1989; Green, Fristoe, and Myerson 1994; Green, Astrid Fry, and Myerson 1994; Holcomb and Nelson 1992; Kirby 1997; Kirby and Marakovic 1995; Loewenstein 1987; Raineri and Rachlin 1993; Marjorie K. Shelley 1993; Thaler 1981). In Thaler's (1981) study, for example, respondents were, on average, indifferent between $15 immediately and $60 in a year, $250 immediately and $350 in a year, and $3000 immediately and $4000 in a year, implying discount rates of 139%, 34%, and 29%. respectively.

4.2.3 The "delay-speedup" asymmetry

Loewenstein (1988) demonstrated that imputed discount rates can be affected dramatically by whether the change in delivery time of an outcome is framed as an acceleration or a delay from some temporal reference point. For example, respondents who didn't expect to receive a VCR for another year would pay an average of $54 to receive it immediately, but those who thought they

would receive it immediately demanded an average of $126 to delay its receipt by a year. Benzion, Rapoport, and Yagil (1989) and Shelley (1993) replicated Loewenstein's findings for losses as well as gains (respondents demanded more to expedite payment than they would pay to delay it).

4.2.4 Preference for improving sequences

In studies of discounting that involve choices between two outcomes — e.g., X at t vs. Y at t' — positive discounting is the norm. Recent research, however, has examined preferences over *sequences* of outcomes (for an overview, see Frederick and Loewenstein 2001; Loewenstein and Prelec 1993), and has found that people often prefer improving sequences to declining sequences. For example, Loewenstein and Nachum Sicherman (1991) found that, for an otherwise identical job, most subjects prefer an increasing wage profile to a declining or flat one (see also Robert Frank 1993). Christopher Hsee, Robert P. Abelson, and Peter Salovey (1991) found that an increasing salary sequence was rated as highly as a decreasing sequence that conferred much more money. Carol Varey and Daniel Kahneman (1990) found that subjects strongly preferred streams of decreasing discomfort to streams of increasing discomfort, even when the overall sum of discomfort over the interval was otherwise identical. Loewenstein and Prelec (1993) found that respondents who chose between sequences of two or more events (e.g., dinners or vacation trips) on consecutive weekends or consecutive months generally preferred to save the better thing for last. Chapman (2000) presented respondents with hypothetical sequences of headache pain that were matched in terms of total pain which either gradually lessened or gradually increased with time. Sequence durations included one hour, one day, one month, one year, five years, and 20 years. For all sequence durations, the vast majority (from 82% to 92%) of subjects preferred the sequence of pain that lessened over time. (See also W.T. Ross, Jr. and I. Simonson 1991).

4.2.5 Violations of independence and preference for spread

The research on preferences over sequences also reveals strong and systematic violations of independence. Consider the following pair of questions (Loewenstein and Prelec 1993):

Imagine that over the next five weekends you must decide how to spend your Saturday nights. From each pair of sequences of dinners below, circle the one you would prefer. "Fancy French"

refers to a dinner at a fancy French Restaurant. "Fancy Lobster " refers to an exquisite lobster dinner at a 4 star restaurant. Ignore scheduling considerations (e.g., your current plans).

Options	first weekend	second weekend	third weekend	fourth weekend	fifth weekend	
A	Fancy French	Eat at home	Eat at home	Eat at home	Eat at home	[11%]
B	Eat at home	Eat at home	Fancy French	Eat at home	Eat at home	[89%]

Options	first weekend	second weekend	third weekend	fourth weekend	fifth weekend	
C	Fancy French	Eat at home	Eat at home	Eat at home	Fancy Lobster	[49%]
D	Eat at home	Eat at home	Fancy French	Eat at home	Fancy Lobster	[51%]

Consumption independence implies that subjects preferring B should also prefer D, but many violated this prediction. A possible explanation for this result is that people generally like to spread consumption over time. Loewenstein and Prelec (1993) provide evidence of such a preference for spread. For example, they asked subjects to imagine that they were given two coupons for fancy ($100) restaurant dinners and to decide when they would use them, ignoring considerations such as holidays, birthdays, etc. For some subjects, no time interval was specified, but others were told that "you can use the coupons at any time between today and 2 years from today." Violating the axiom of revealed preference, subjects in the condition with the two-year constraint requested both dinners at a *later* time than those who faced no constraint; they wanted to eat the first dinner after 8 weeks (as opposed to 3 weeks for the no-constraint condition), and the second dinner after 31 weeks (in contrast to 13 weeks when there was no constraint). The difference between the two conditions can be explained in terms of the preference for spread: Subjects behaved as if they were attempting to "cover" some implicit interval, and the two-year constraint seems to have enlarged this implicit interval over and above its unconstrained magnitude. Notice that this preference for spread goes beyond what would be predicted by declining marginal utility in individual periods, or even allowing utility interactions across adjacent periods (as suggested by Itzhak Gilboa 1989).

4.3 *Are these "anomalies" mistakes or preferences?*

Unlike other types of "effects" that have been documented in other domains of judgment and choice (such as the "conjunction fallacy" discovered by Tversky and Kahneman 1983), the patterns of preferences regarded as DU "anomalies" do not necessarily violate any standard or principles that people believe they should uphold. Even when the choice pattern is pointed out to people, they do not regard themselves as having made a mistake. For example, in unpublished research, Frederick (1996) found evidence that the magnitude effect is *more* pronounced when subjects evaluate both "small" and "large" amounts than when they evaluate either one. Specifically, respondents discounted small amounts more extremely if the preceding judgment involved large amounts than if they made no preceding judgment. Since respondents did not attempt to coordinate their responses to conform to DU's postulates, it suggests that respondents consider the different discount rates to be normatively appropriate. Similarly, even though Loewenstein and Sicherman (1991) informed respondents that a decreasing wage profile ($27,000, $26,000,….$23,000) would (via appropriate saving and investing) permit strictly more consumption in every period than the corresponding increasing wage profile with an equivalent nominal total ($23,000, $24,000,….$27,000), respondents still preferred the increasing sequence. Respondents may have suspected that they could not exercise the required self control to maintain their desired *consumption* sequence, or have felt a general leeriness about the significance of a declining wage. As these examples illustrate, many DU "anomalies" exist as "anomalies" only by reference to a model, which is both normatively dubious and constructed without regard to its descriptive validity.

5. *Alternative Models*

In response to the anomalies just enumerated, as well as other intertemporal choice phenomena that are inconsistent with the DU model, a variety of alternate theoretical models have been developed. Most of these models modify the DU model so as to incorporate additional considerations. Some models attempt to achieve greater descriptive realism by relaxing the assumption of constant discounting. Other models incorporate additional considerations into the instantaneous utility function, such as habit formation or utility from anticipation. Yet another category of models departs from the DU model in more extreme ways, e.g., by viewing

individuals as collections of temporally situated competing "selves."

5.1 *Models of hyperbolic discounting*

In the economics literature, R.H. Strotz (1955-1956) was the first to consider alternatives to exponential discounting. He recognized that for any discount function other than exponential, a person would have time-inconsistent preferences, and might therefore change her mind as time passes.[16] Strotz saw "no reason why an individual should have such a special discount function" (p. 172), and he proposed two techniques for analyzing the behavior of a person who foresees how her preferences will change over time, the "strategy of precommitment" and the "strategy of consistent planning."[17] While Strotz did not posit any specific alternative functional forms, he did suggest that "special attention" be given to the case of declining discount rates.

Motivated by the evidence discussed in Section 4.1, there has been a recent surge of interest among economists in the implications of declining discount rates and hyperbolic discounting (beginning with David Laibson 1994,1997a). This literature has used a particularly simple functional form which captures the essence of hyperbolic discounting:

$$D(k) = \begin{cases} 1 & if\ k = 0 \\ bd^{k} & if\ k > 0. \end{cases}$$

This functional form was first introduced by E.S. Phelps and Pollak (1968) to study intergenerational altruism, and was first applied to individual decision making by Jon Elster (1979). It assumes that the per-period discount rate between now and next period is $\frac{1-bd}{bd}$ whereas the per-period discount rate between any two future periods is $\frac{1-d}{d} < \frac{1-bd}{bd}$. Hence, this *(b,d)* formulation assumes a declining discount rate between this period and next, but a constant discount rate thereafter. While this assumption is not empirically accurate — empirical studies typically show that discount rates continue to decline as the delay interval increases — the *(b,d)* formulation is highly tractable and reveals many of the *qualitative* implications of hyperbolic

[16] Strotz implicitly assumes stationary discounting.

[17] Building on Strotz's strategy of consistent planning, a number of researchers addressed the question of whether there exists a consistent path for general non-exponential discount functions. See in particular Robert Pollak (1968), Bezalel Peleg and Menahem Yaari (1973), and Steven Goldman (1980).

discounting.

Laibson and his collaborators have used the *(b,d)* formulation to explore the implications of hyperbolic discounting for consumption-saving behavior. Hyperbolic discounting leads a person to consume more than she would like (or, equivalently, to under-save). Laibson (1997a) explores the role of illiquid assets, such as housing, as an imperfect commitment technology, emphasizing how a person could limit over-consumption by tying up her wealth in illiquid assets. Laibson (1998) explores consumption-saving decisions in a world without illiquid assets (or any other commitment technology). These papers both describe how hyperbolic discounting might explain some stylized empirical facts, such as the excess comovement of income and consumption, the existence of asset-specific marginal propensities to consume, low levels of precautionary savings, consumption discontinuities at retirement, and the correlation of measured levels of patience with age, income, and wealth. Laibson, Andrea Repetto and Jeremy Tobacman (1998), and George-Marios Angeletos, Laibson, Repetto, Tobacman and Stephen Weinberg (2001) calibrate models of consumption-saving decisions, using both exponential discounting and *(b,d)* hyperbolic discounting. By comparing simulated data to real-world data, they demonstrate how hyperbolic discounting can better explain a variety of empirical observations in the consumption-saving literature. In particular, Angeletos, Laibson, Repetto, Tobacman and Weinberg (2001) describe how hyperbolic discounting is better able to explain the coexistence of high pre-retirement wealth, low liquid asset holdings (relative to income levels and illiquid asset holdings), and high credit-card debt.

Carolyn Fischer (1997) and O'Donoghue and Rabin (1999c,2001a) have applied *(b,d)* preferences to procrastination, where hyperbolic discounting leads a person to put off carrying out an onerous activity more than she would like.[18] O'Donoghue and Rabin (1999c) examine the implications of hyperbolic discounting for contracting when a principal is concerned with combating procrastination by an agent. They show how incentive schemes with "deadlines" may be a useful screening device to distinguish efficient delay vs. inefficient procrastination. O'Donoghue and Rabin (2001a) explore procrastination when a person must choose not only *when* to complete a task, but also must choose *which task* to complete — e.g., a person might be able to choose a low-effort task that yields small benefits or a high-effort task that yields large

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[18]While not framed in terms of hyperbolic discounting, George Akerlof's (1991) model of procrastination is

benefits. They show how providing people with new options that are better from a long-run perspective but very onerous to carry out might lead more people to procrastinate, because people plan to do a new option, but may repeatedly put off incurring the high immediate cost. They also show how people may be more prone to procrastinate on important projects, because people are more ambitious on more important projects, and the more ambitious people are, the more prone they are to procrastinate on delivering the effort required to satisfy those ambitions.

O'Donoghue and Rabin (1999a,2000), Jonathan Gruber and Botond Koszegi (2000), and Juan D. Carrillo (1999) have applied *(b,d)* preferences to addiction. These researchers describe how hyperbolic discounting can lead people to over-consume harmful addictive products**,** and explore the degree of harm caused by such over-consumption. Finally, Carrillo and Thomas Mariotti (2000) and Roland Benabou and Jean Tirole (2000) have examined how *(b,d)* preferences might influence a person's decision to acquire information. In particular, whereas the standard economic model implies information is always valuable, Carrillo and Mariotti point out how hyperbolic discounting can lead to "strategic ignorance" — not acquiring free information because doing so increases the likelihood of future misbehavior.

5.1.1 Self awareness

An important issue arises when a person has time-inconsistent preferences: Is she aware that her preferences will change over time? Strotz (1955-1956) and Pollak (1968) proposed two extreme alternatives: At one extreme, a person could be completely "naï ve" and believe that her future preferences will be identical to her current preferences. At the other extreme, a person could be completely "sophisticated" and correctly predict how her preferences will change over time. While casual observation and introspection suggest that most people lie somewhere in between these two extremes, the behavioral evidence is quite limited. The best evidence comes from the studies by Ariely and Wertenbroch (in press) that we described in Section 4.1. The fact that many students in the free-choice condition — the students that chose whether or not to impose deadlines on themselves — did in fact choose to impose deadlines on themselves suggests that people have some awareness of how their preferences change over time, and the need for commitment. But since many students did not impose such deadlines on themselves, or imposed suboptimal deadlines, these studies also suggest that many people are, to some degree, naï ve

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formally equivalent to a hyperbolic model.

about how their preferences change over time.

O'Donoghue and Rabin (1999b) examine the importance of people's sophistication about their own time inconsistency. Being sophisticated (as opposed to naïve) means that a person's behavior is partially driven by reactions to anticipated future misbehavior. Indeed, many of the results described above, such as avoiding information or using illiquid assets as an imperfect commitment technology, are driven entirely by such reactions to future misbehavior. Other results, such as over-consumption or procrastination, are more robust to assumptions about awareness. But even for those results, the degree of misbehavior may depend critically on the degree of sophistication. To understand such effects, O'Donoghue and Rabin (2001a) introduce a formal model of partial naïvete, where a person is aware that she will have future self-control problems but underestimates their magnitude. They show that severe procrastination cannot occur under complete sophistication, but can arise even if the person is only a little naïve. For more discussion on the role of sophistication vs. naivete, see O'Donoghue and Rabin (2001b).

The degree of sophistication vs. naiveté has important implications for public policy. If people are sufficiently sophisticated about their own self-control problems, then it may be welfare enhancing to provide commitment devices (although the question arises whether the market would provide them). If people are sufficiently naïve, in contrast, then they won't see the benefits of commitment devices. In that case, policies might be aimed at providing incentives for people to use commitment devices, so that they can experience unanticipated commitment benefits. Alternatively, policies might be aimed at educating people about loss of control, although some sort of incentives would still be required because people would not see the value of the education.

5. 2 *Models that enrich the instantaneous utility function*

In addition to more realistic models of discounting, intertemporal-choice researchers have also proposed models that enrich the instantaneous utility function. Many of these models were proposed in response to the DU anomalies discussed in Section 4.2. A persistent theme is that many empirical observations of differential discounting can be understood as reflecting richer features of the instantaneous utility function. In other words, a person who has a unitary time preference may exhibit differential discounting because of some richer features of her instantaneous utility function. (In Section 6, we further discuss the theme of how empirical

studies might misspecify the instantaneous utility function.)

5.2.1 *Habit-formation models*

James Duesenberry (1952) was the first economist to propose the idea of "habit formation" — that the level of past consumption can affect the utility from current consumption. This idea was more formally developed by Pollak (1970) and Harl Ryder and Geoffrey Heal (1973). In habit formation models, the period-t instantaneous utility function takes the form $u(c_t; c_{t-1}, c_{t-2}, ...)$ where $\partial^2 u / \partial c_t \partial c_{t'} > 0$ for $t' < t$. For simplicity, most such models assume that all effects of past consumption for current utility enter through a state variable. That is, they assume that period-t instantaneous utility function takes the form $u(c_t; z_t)$ where z_t is a state variable that is increasing in past consumption and $\partial^2 u / \partial c_t \partial z_t > 0$. Both Pollak (1970) and Ryder and Heal (1973) assume that z_t is the exponentially weighted sum of past consumption — that is, $z_t = \sum_{i=1}^{\infty} g^i c_{t-i}$.

Habit formation may lead a person to choose an increasing, decreasing, or non-monotonic consumption profile, depending on whether her initial "habit stock" is low or high and whether current consumption has a positive or negative "internality" on future well-being.[19] Hence, habit formation could potentially explain the preference for improvement over time, and more generally make a person look more or less "patient" (lower or higher rate of time preference) than she really is, depending on circumstances.

In recent years, habit-formation models have been used in many specific applications. Gary Becker and Kevin Murphy (1988) use a habit-formation model to study addictive products, and explore the effect of past and future prices on current consumption.[20] Others have shown how habit formation may be useful in improving the asset-pricing implications of business-cycle models (Urban Jermann (1998), Michele Boldrin, Lawrence Christiano, and Jonas Fisher (2001)) and various asset-pricing anomalies such as the equity-premium puzzle (Andrew Abel 1990; John

[19]The term "internality" was coined by Herrnstein, Loewenstein, Prelec, and William Vaughan (1993), who define an internality to be a "within-person externality". Habit-formation models often require regularity conditions to be well-behaved. A similar problem arises in models of reference-dependent utility.

[20]For rational-choice models building on Becker and Murphy's framework, see Athanasios Orphanides and David Zervos (1995), Ruqu Wang (1997), and Suranovic, Goldfarb, and Leonard (1999). For addiction models that incorporate hyperbolic discounting, see O'Donoghue and Rabin (1999a,2000), Gruber and Koszegi (2000), and Carrillo (1999).

Campbell and John Cochrane 1999; George M. Constantinides 1990). Some recent papers have shown that habit formation may be useful in explaining some empirical puzzles in macroeconomics. Whereas standard growth models suggest that high saving rates cause high growth, recent evidence suggests the causality runs in the opposite direction. Christopher Carroll, Jody Overland, and David Weil (2000) show how, with habit formation, high growth can lead to high saving rates. Jeffrey Fuhrer (2000) shows how habit formation might explain the recent finding that aggregate spending tends to have a gradual "hump-shaped" response to various shocks. The key feature of habit formation that drives many of these results is that, after a shock, consumption adjustment is sluggish in the short term but not the long term.

5.2.2 *Reference-point models*

Closely related to, but conceptually distinct from, habit-formation models are models of reference-dependent utility, which incorporate ideas from prospect theory (Kahneman and Tversky 1979; Tversky and Kahneman 1991). According to prospect theory, outcomes are evaluated using a value function defined over departures from a reference point — in our notation, the period-t instantaneous utility function takes the form $u(c_t, r_t) = v(c_t - r_t)$. The reference point, r_t, might depend on past consumption, expectations, social comparison, status quo, etc. A second feature of prospect theory is that the value function exhibits *loss aversion* – negative departures from one's reference consumption levels decrease utility by a greater amount than positive departures increase it. A third feature of prospect theory is that the value function exhibits *diminishing sensitivity* for both gains and losses, which means that the value function is concave over gains and convex over losses.[21]

Loewenstein and Prelec (1992) applied such a value function to intertemporal choice in order to explain the magnitude effect, the sign effect, and the delay-speedup asymmetry. Specifically, if the elasticity of the value function is increasing in the magnitude of outcomes, then people will discount smaller magnitudes more than larger magnitudes. Intuitively, the elasticity

[21] Reference-point models sometimes assume there is a direct effect of the consumption level or reference level, so that $u(c_t, r_t) = v(c_t - r_t) + w(c_t)$ or $u(c_t, r_t) = v(c_t - r_t) + w(r_t)$. Some habit-formation models could be interpreted as reference-point models, where the state variable z_t is the reference point. Indeed, many habit-formation models, such as Pollak (1970) and Constantinides (1990), assume instantaneous utility functions of the form $u(c_t - z_t)$, although they typically assume neither loss aversion nor diminishing sensitivity.

condition implies that two large rewards (say, $200 and $100) are psychologically more different than two proportionately scaled down outcomes (say, $20 and $10) — that is, $\frac{v(200)}{v(100)} > \frac{v(20)}{v(10)}$. Consequently, even if a person's time preference is unitary, he will be more willing to wait for a delayed larger outcome the bigger is the scale of both outcomes. Similarly, if the value function for losses is more elastic than the value function for gains, then people will discount gains more than losses. Finally, such a model helps explain the delay-speedup asymmetry (Loewenstein 1988). Shifting consumption in any direction is made less desirable by loss aversion, since one loses consumption in one period and gains it in another. When delaying consumption, loss aversion operates in the same direction as time discounting, creating a powerful aversion to delay. When expediting consumption, loss aversion opposes time discounting, resulting in a relatively weak desire for speedup (and, occasionally, even an aversion to it).

David Bowman, Deborah Minehart, and Rabin (1999) apply a reference-dependent model with loss aversion to savings-consumption decisions. Their model predicts an asymmetry in how people respond to unexpected "news" about their (stochastic) income. Specifically, people should show much more resistance to reducing their consumption after unexpected bad news than they do to increasing their consumption after unexpected good news. This asymmetry with respect to *unexpected* news about income implies the reverse asymmetry with respect to *expected* income growth: Consumption growth should react more to a decline in expected income growth than it does to an increase. Two studies by John Shea (1995a;1995b) support this prediction. Shea (1995b) uses data from teacher's unions in which wages are set one year in advance, and finds that consumption growth responds more to wage decreases than to wage increases. Shea (1995a) finds further evidence of the same asymmetry using aggregate U.S. data.

5.2.3 *Models incorporating utility from anticipation*

Some alternative models build on the notion of "anticipal" utility discussed by the elder and younger Jevons. If people derive pleasure not only from current consumption, but also from anticipating future consumption, then current instantaneous utility will depend positively on future consumption — that is, the period-t instantaneous utility function would take the form $u(c_t; c_{t+1}, c_{t+2}, ...)$ where $\partial u / \partial c_{t'} > 0$ for $t' > t$. Loewenstein (1987) advanced a formal model which assumes that a person's instantaneous utility is equal to the utility from consumption in that period plus some function of the discounted utility of consumption in future periods. Specifically,

if we let *v(c)* denote utility from actual consumption, and assume this is the same for all periods, then:

$$u(c_t; c_{t+1}, c_{t+2}, ...) = v(c_t) + a[g\, v(c_{t+1}) + g^2 v(c_{t+1}) + ...] \text{ for some } g < 1.$$

Loewenstein describes how utility from anticipation may play a role in many DU anomalies. Because near-term consumption delivers only consumption utility whereas future consumption delivers both consumption utility and anticipatory utility, anticipatory utility provides a motive for a preference for improvement, and for why people often get unpleasant outcomes over with quickly instead of delaying them as discounting would predict. It provides a possible explanation for why people discount different goods at different rates, because utility from anticipation creates a downward bias on estimated discount rates, and this downward bias is larger for goods that create more anticipatory utility. If, for instance, dreading future bad outcomes is a stronger emotion than savoring future good outcomes, which seems highly plausible, then utility from anticipation would generate a sign effect. Finally, anticipatory utility gives rise to a form of time inconsistency that is quite different from that which arises from hyperbolic discounting. To see this, consider a person's MRS between periods *t* and *t+1*. As period *t* approaches, total anticipatory utility from periods *t* and *t+1* both decrease, but that for period *t* decreases at a faster rate (since it is sooner). Hence, the MRS between periods *t* and *t+1* decreases as the person approaches period *t*, and so the person puts less relative weight on period *t* as it approaches.[22]

Loewenstein's model of anticipatory utility applies to deterministic outcomes. In a recent paper, Caplin and Leahy (2001) point out that many anticipatory emotions, such as anxiety or suspense, are driven by uncertainty about the future, and they propose a new model that modifies expected-utility theory to incorporate such anticipatory emotions. They then show that incorporating anxiety into asset-pricing models may help explain the equity premium puzzle and the risk-free rate puzzle, because anxiety creates a taste for risk-free assets and an aversion to risky assets. Like Loewenstein, Caplin and Leahy also emphasize how anticipatory utility can lead

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[22] To see this formally, consider the MRS between periods 2 and 3 when $u(c_t; c_{t+1}, c_{t+2}, ...) = v(c_t) + a[g\, v(c_{t+1}) + g^2 v(c_{t+1}) + ...]$ and there is no discounting. From a period-1 perspective, $MRS^1_{2,3} = \frac{(1+ag)}{(1+ag+ag^2)} \frac{v'(c_2)}{v'(c_3)}$, whereas from a period-2 perspective, $MRS^2_{2,3} = \frac{1}{(1+ag)} \frac{v'(c_2)}{v'(c_3)}$.

to time inconsistency. See also Koszegi (2001) for further discussion on the possible implications of anticipatory feelings.

5.2.4 *Visceral influences*

A final alternative model of the utility function incorporates "visceral" influences such as hunger, thirst, sexual desire, physical pain, cravings, etc. Loewenstein (1996,2000b) argues that economics should take more seriously the implications of such transient fluctuations in tastes. Formally, visceral influences mean that the person's instantaneous utility function takes the form $u(c_t, d_t)$ where d_t represents the vector of visceral states in period t. Visceral states are (at least to some extent) endogenous — e.g., a person's current hunger depends on how much she has consumed in previous periods — and therefore lead to consumption interdependence.

The introduction of visceral influences has important implications for intertemporal choice. First, by creating a strong desire to engage in certain behaviors — e.g., an extremely hungry person has a strong desire to eat — visceral influences can give rise to behaviors that look extremely impatient or even impulsive. In a closely related paper, Laibson (2001) talks about the role of "cues" in influencing visceral states, and describes how, if one fails to take account of the impact of the visceral states on momentary utility, such visceral states can give rise to behavior that appears myopic. Similarly, visceral influences provide an alternative account of the time-based preference reversals that are typically attributed to hyperbolic time discounting, because the immediate availability of a reward is one of the cues that has been shown to activate appetitive visceral states. Moreover, the cues that trigger visceral states can be extremely varied — cues include the sight, smell, or even mental image of the reward object, or the time of day when, or setting where, the reward object is typically consumed. Hence, the discussion of cues may help to generate new predictions about the specific circumstances (other than immediate availability of a reward object) that can trigger myopic behavior.

The fact that visceral states are endogenous introduces issues of state-management (as discussed by Loewenstein 1999, and Laibson 2001 under the rubric of "cue management"). While the model (at least the rational version of it) predicts that a person would want herself to use drugs if she were to experience a strong enough craving, it also predicts that she might want to prevent ever experiencing such a strong craving. Hence, visceral influences can give rise to a preference for commitment in the sense that the person may want to avoid certain situations.

There is some question, however, whether visceral influences can be fully understood as merely exerting a momentary effect on preferences. First, there is evidence that people underestimate both the impact of future visceral influences on their own future behavior, and how short-lived certain visceral influences, such as sexual desire, cravings, and anger, may be. As a result, people may not react optimally to visceral influences (Loewenstein 1996,1999,2000b; see also our discussion of *projection bias* below). Second, people often would prefer not to respond to intense visceral factors such as rage, fear, or lust, sometimes (at some level of consciousness) even at the moment of succumbing to their influence. A way to understand such effects is to apply the distinction between "experienced utility" and "decision utility" proposed by Kahneman (1994). On one hand, the person is characterized by her "experienced utility", which reflects her welfare — what she would like to maximize. On the other hand, she is characterized by her "decision utility," which is what she maximizes when she makes decisions (perhaps aware or perhaps unaware that she is not maximizing experienced utility). Kahneman discusses a variety of reasons why decision utility might differ from experienced utility. An alternative way to conceptualize the effects of visceral factors is not as influencing experienced utility, but rather as influencing decision utility, and hence driving a further wedge between experienced utility and decision utility. See Douglas Bernheim and Antonio Rangel (2001) for a model of visceral factors and addiction framed in these terms.

5.3 *More "extreme" alternative perspectives*

The alternative models above involve modifications to the DU model designed to improve its descriptive realism. Some alternatives posit more extreme departures from the DU model.

5.3.1 *Projection Bias*

In many of the alternative models of utility discussed above, current consumption influences future well-being. Hence, to properly weigh an intertemporal trade-off, a person must predict how her current consumption will change her future well-being. Essentially all economic models of changing tastes make the natural assumption (for economists) that such predictions are correct — that people have "rational expectations". However, Loewenstein, O'Donoghue, and Rabin (2000) posit that while people may anticipate the qualitative nature of their changing preferences, they tend to underestimate the magnitude of these changes — a systematic

misprediction which they label *projection bias*.

Loewenstein, O'Donoghue, and Rabin review a broad array of evidence that demonstrates the prevalence of projection bias, and then model it formally. To illustrate their model, consider projection bias in the realm of habit formation. As discussed above, suppose the period-t instantaneous utility function takes the form $u(c_t ; z_t)$, where z_t is a state variable that captures the effects of past consumption. Projection bias arises when a person whose current state is z_t must predict her future utility given future state z_t. Projection bias implies that the person's prediction $\tilde{u}(c_t ; z_t \mid z_t)$ will lie in between her true future utility $u(c_t ; z_t)$ and her utility given her current state $u(c_t ; z_t)$. A particularly simple functional form is $\tilde{u}(c_t ; z_t \mid z_t) = (1-a)\, u(c_t ; z_t) + a\, u(c_t ; z_t)$ for some $a \in [0,1]$.

Projection bias may arise in any situation in which tastes change over time, due to such effects as habit formation, changing reference points, or changes in visceral states. It can have important behavioral and welfare implications. For instance, in the realm of habit formation, projection bias leads a person to under-appreciate how current consumption reduces the utility from future consumption, and hence leads to over-consumption. Also, to the extent that intertemporal choices are influenced by projection bias, measurements of time preference may be distorted.

5.3.3 *Mental-accounting models*

Some researchers have proposed that people do not treat all money as fungible, but instead assign different types of expenditures to different "mental accounts" (see Thaler 1999 for a recent overview). Such models can give rise to realistic patterns of intertemporal behavior that seem odd when viewed through the lens of the DU model. Thaler (1985), for instance, suggests that small amounts of money are coded as spending money, whereas larger amounts of money are coded as savings, and that a person is more willing to spend out of the former account. This conceptualization might explain why a person behaves in a spendthrifty way for small purchases (a new pair of shoes), while the same person behaves frugally for large purchases (a new dining-room table).[23] Shlomo Benartzi and Thaler (1995) suggest that people treat their financial

[23] While it seems possible that this conceptualization could explain the magnitude effect as well, the magnitude effect is found for very "small" amounts (e.g., between $2 and $20 in Ainslie and Haendel 1983), and for very "large amounts" (e.g., between $10,000 and $1,000,000 in Raineri and Rachlin 1993). It seems highly unlikely

portfolios as a mental account, and emphasize the importance of how often people "evaluate" this account. They argue that if people review their portfolios once a year or so, and if people experience joy or pain from any gains or losses, as assumed in Kahneman and Tversky's (1979) prospect theory, then such "myopic loss aversion" represents a plausible explanation for the equity premium puzzle.

Prelec and Loewenstein (1998) propose another way in which mental accounting might influence intertemporal choice. They posit that payments for consumption confer immediate disutility or "pain of paying," and that people keep mental accounts for different consumption items that link the consumption of that item with the payments for that item. They also assume that people engage in "prospective accounting." According to prospective accounting, when consuming, people think only about current and future payments; past payments don't cause pain of paying. Likewise, when paying, the pain of paying is buffered only by thoughts of future consumption. The model suggests that seemingly equivalent ways of financing a purchase can lead to different decisions. Similarly, a person might have different financing preferences depending on the consumption item (e.g., they should prefer to prepay for a vacation that is consumed all at once vs. a new car that is consumed over many years). The model generates a preference for fixed-fee pricing schemes with zero marginal costs over pay-as-you-go schemes that tightly couple marginal payments to marginal consumption. The model also suggests that inter-individual heterogeneity might arise from differences in the degree to which people experience the pain of paying rather than differences in time preference. On this view, the miser is not someone with a low rate of time preference, but rather someone who experiences intense pain of paying.

5.3.4 *Choice bracketing*

One important aspect of mental accounting is that a person does not make all intertemporal choices simultaneously, but rather makes at most a few choices at any one time, and ignores interdependencies between these choices and other choices. As a result, how choices are "bracketed" can influence intertemporal choices. Specifically, intertemporal choices are often influenced by a variety of contradictory motives, and because different types of bracketing can

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that respondents would consistently code the lower amounts as spending and the higher amount as savings across all of these studies.

highlight different motives, bracketing can have an important impact on the choices people make. This perspective is implicit in several of the models we discuss above, such as models of reference-dependent utility. For an overview of research related to choice bracketing, see Read, Loewenstein, and Rabin (1999).

To illustrate, consider the conflict between impatience and a preference for improvement over time. Loewenstein and Prelec (1993) demonstrated that the relative importance of these two motives can be altered by the way that choices are bracketed. They asked one group of subjects to choose between having dinner at a fine French restaurant in one month vs. two months. Most subjects chose one month, presumably reflecting impatience. They then asked another group to choose between eating at home in one month followed by eating at the French restaurant in two months vs. eating at the French restaurant in one month followed by eating at home in two months. The majority now wanted the French dinner in two months. For both groups, dinner at home was the most likely alternative to the French dinner; but it was only when the two dinners were expressed as a sequence that the preference for improvement became a basis for decision.

An interesting question for which choice bracketing may be important is whether a preference for improvement merely reflects the combined effect of other motives, such as habit formation or anticipatory utility, or whether it is something unique. Viewed from an integrated decision-making perspective, it perhaps seems natural to conclude the former, because it is not clear why improvement for its own sake should be valuable. But when viewed from a choice-bracketing perspective, the latter interpretation becomes more plausible. Making non-integrated decisions requires that the person have some choice heuristic for evaluating options. A natural assumption is that these choice heuristics are designed to induce behavior similar to what integrated decision making would yield (of course, there is no reason to assume the person is aware of where the choice heuristics come from). Hence, even if a preference-for-improvement choice heuristic originated from considerations of habit formation or anticipatory utility, a person using this choice heuristic may feel that improvement for its own sake has value.[24]

Loewenstein and Prelec (1993) develop a (choice-heuristic) model for how people evaluate choices over sequences. They assume that people consider a sequence's discounted utility, its degree of improvement, and its degree of spread. The key ingredients of the model are

[24]This interpretation of the preference for improvement as a choice heuristic for evaluating sequences perhaps explains why it is subject to powerful framing effects (see for instance Loewenstein and Prelec 1993), because what

"gestalt" definitions for improvement and spread. In other words, they develop a formal measure of the degree of improvement and the degree of spread for any sequence. They show that their model can explain a wide range of sequence anomalies, including observed violations of independence, and that it predicts preferences between sequences much better than other models that incorporate similar numbers of free parameters (e.g., a model with an entirely flexible time discount function).

5.3.5 *Multiple-self models*

An influential school of theorists have proposed models that view intertemporal choice as the outcome of a conflict between multiple selves. Most multiple-self models postulate myopic selves who are in conflict with more farsighted ones, and often draw analogies between intertemporal choice and a variety of different models of interpersonal strategic interactions. Some models (e.g., Ainslie and Nick Haslam 1992; Thomas C. Schelling 1984; Gordon C. Winston 1980) assume that there are two agents, one myopic and one far-sighted, who alternately take control of behavior. The main problem with this approach is that there is little discussion about when and why either type of agent emerges. In addition, there is an inherent asymmetry between players that is not captured in these types of models: Whereas these models assume a battle between the two agents, in reality myopic selves rarely if ever attempt to control the behavior of far-sighted selves. The heroin addict, for instance, while taking heroin, rarely if ever attempts to prevent tomorrow's remorseful self from denying tomorrow's addict the heroin.

Responding, in part, to this problem, Thaler and Hersh Shefrin (1981) proposed a "planner-doer" model which draws upon principal-agent theory. In their model, a series of myopic "doers", who care only about their own immediate gratification (and have no affinity for future or past doers), interact with a unitary "planner" who cares about the present and future in a more even-handed fashion. The model focuses on the strategies employed by the planner to control the behavior of the doers. The model highlights the observation, later discussed at length by Loewenstein (1996), that the far-sighted perspective is often much more constant than the myopic perspective. For example, people are often consistent in recognizing the need to maintain a diet. Yet they periodically violate their own desired course of action — often recognizing even at the moment of doing so that they are not behaving in their own self-interest.

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constitutes a sequence is so subjective.

Yet a third type of multiple-self model draws connections between intertemporal choice and models of multi-person strategic interactions (Elster 1985). The essential insight that these models capture is that, much like cooperation in a social dilemma, self-control often requires the cooperation of a series of temporally situated selves. When one self "defects" by opting for immediate gratification, the consequence can be a kind of unraveling or "falling off the wagon" whereby subsequent selves follow the precedent.

Few of these multiple-self models have been expressed formally, and even fewer have been used to derive testable implications that go much beyond the intuitions that inspired them in the first place. Perhaps, however, it is unfair to criticize the models for these shortcomings. Instead, the models are probably best viewed as metaphors intended to highlight specific aspects of intertemporal choice. Specifically, multiple-self models have been used to make sense of the wide range of self-control strategies that people use to regulate their own future behavior. Moreover, these models provided much of the inspiration for more recent formal models of sophisticated hyperbolic discounting (following Laibson 1994,1997a).

5.3.6 *"Temptation utility"*

Most models of intertemporal choice — indeed, most models of choice in any framework — assume that options not chosen are irrelevant to a person's well-being. A recent paper by Gul and Pesendorfer (2001) suggests that people have temptation preferences, wherein they experience disutility from not choosing the most immediately enjoyable option. An implication of their theory is that a person might be better off if some particularly tempting option were not available, even if she doesn't choose that option. As a result, she may be willing to pay in advance to eliminate that option, or in other words, she may have a preference for commitment.

5.3.7 Conclusion: *Combining insights from different models*

Many behavioral models of intertemporal choice focus on a single modification to the DU model, and ask how much additional realism that single modification yields. But many empirical phenomena are perhaps best understood as reflecting the interaction of multiple phenomena. For instance, the preference for improvement may interact with hyperbolic time discounting to produce interesting and realistic preferences for U-shaped sequences — e.g., for jobs that offer a signing bonus and a salary that increases gradually over time. Because hyperbolic discounting

involves high short-term discounting that may swamp the preference-for-improvement motive, a person might choose a consumption path that is decreasing over time in the short-term. But since hyperbolic discounting entails low long-term discounting that may be weaker than the preference-for-improvement motive, the same person's consumption path may be increasing over time in the long-term.

As another example, the introduction of visceral influences into models of hyperbolic discounting may have the potential to explain more fully the phenomenology of impulsive choices. Hyperbolic-discounting models predict that people respond disproportionately to immediate costs and benefits, and visceral influences create powerful but momentary influences on immediate utilities. In combination, the two assumptions may have the ability to explain a wide range of impulsivity and self-control phenomena.

6. *Measuring Time Discounting*

The DU model assumes that a person's time preference can be captured by a single discount rate, r. Over the past three decades, numerous published articles have reported estimates of discount rates, some from observations of "real world" behaviors (e.g., the choice between electrical appliances which differ in their initial purchase price and long-run operating costs) and others from experimental elicitation procedures (e.g., "Would you prefer $100 today or $150 one year from today?"). Table 2 summarizes the implicit discount rates (and also some other features) from a number of these studies.

(Table 2 here)

Figure 2 plots the estimated discount *factor* for each study against the publication date for that study, where the discount *factor* is $\delta = 1/(1+\rho)$.[25] This figure reveals three noteworthy observations. First, there is tremendous variability in these estimates (the corresponding implicit annual discount rates range from –6% to infinity). Second, these estimates clearly have not

[25] In some cases, the estimates are computed from the median respondent. In other cases, the authors reported the mean discount rate.

become more precise over time (in contrast to estimates of physical phenomena such as the speed of light). Third, there is a predominance of high discount rates, as most of the data points are well below unity.

(Figure 2 here)

In this section, we provide an overview and critique of this empirical literature with an eye towards understanding these observations. We first discuss a variety of confounding factors, such as intertemporal arbitrage, uncertainty, and expectations of changing utility functions. These considerations typically are not regarded as legitimate components of time preference *per se*, but they can affect both experimental responses and real-world choices. With these confounding factors in mind, we then review the procedures used to estimate discount rates. This section reiterates a theme from Section 5: To truly understand intertemporal choices, one must recognize the influence of many considerations besides pure time preference.

6.1 *Confounding factors*

A wide variety of procedures have been used to estimate discount rates, but most apply the same basic approach. Some actual or reported intertemporal preference is observed, and researchers then compute the discount rate that this preference implies using a "financial" or net present value (NPV) calculation. For instance, if a person demonstrates indifference between 100 widgets now and 120 widgets in one year, the implicit (annual) discount rate, r, would be 20%, because that value would satisfy the equation $100 = (1/(1+\rho))120$. Similarly, if a person is indifferent between an inefficient low-cost appliance and a more efficient one that costs $100 extra but saves $20 a year in electricity over the next ten years, the implicit discount rate, r, would equal 15.1%, because that value would satisfy the equation $100 = \sum_{t=1}^{10}(1/(1+r))^t 20$.

Although this is an extremely widespread approach for measuring discount rates, it relies on a variety of additional (and usually implicit) assumptions, and hence is subject to a variety of confounding factors.

6.1.1 *Consumption reallocation*

The calculation outlined above assumes a sort of "isolation" in decision making.

Specifically, it treats the objects of intertemporal choice as discrete, unitary, dated events; it assumes that people entirely "consume" the reward (or penalty) at the moment it is received, as if it were an instantaneous burst of utility. Furthermore, it assumes that people don't shift consumption around over time in anticipation of the receipt of the future reward or penalty. These assumptions are rarely exactly correct, and may sometimes be bad approximations. Choosing between $50 today vs. $100 next year, or choosing between 50 lbs. of corn today vs. 100 lbs. next year, are not the same as choosing between 50 utils today and 100 utils next year, as the calculations imply. Rather, they are more complex choices between the various streams of consumption that those two dated rewards make possible.

6.1.2 *Intertemporal arbitrage*

In theory, choices between tradable rewards, such as money, should not reveal anything about time preferences. As Victor Fuchs (1982) and others have noted, if capital markets operate effectively (if monetary amounts at different times can be costlessly exchanged at a specified interest rate), choices between dated monetary outcomes can be reduced to merely selecting the reward with the greatest net present value (using the market interest rate).[26] To illustrate, suppose a person prefers $100 now to $200 ten years from now. While this preference *could* be explained by imputing a discount rate on future utility, the person might be choosing the smaller immediate amount because she believes that through proper investment she can turn it into more than $200 in ten years, and, thus, enjoy more than $200 worth of consumption *at that future time*. In short, the presence of capital markets should cause imputed discount rates to converge on the market interest rate.

Thus, studies that impute discount rates from choices among tradable rewards assume that respondents ignore opportunities for intertemporal arbitrage, because the respondents either are unaware of capital markets or are unable to exploit them.[27] The latter assumption may sometimes

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[26] Meyer (1976) expresses this point: "..if we can lend and borrow at the same rate..., then we can simply show that, regardless of the fundamental orderings on the c's [consumption streams], the induced ordering on the xs [sequences of monetary flows] is given by simple discounting at this given rate ...We could say that the market assumes command and the market rate prevails for monetary flows."

[27] Arguments about violations of the discounted utility model assume, as Pender (1996, pp. 282-283) notes, "that the results of discount rate experiments reveal something about intertemporal preferences directly. However, if agents are optimizing an intertemporal utility function, their opportunities for intertemporal arbitrage are also important in determining how they respond to such experiments.....when tradable rewards are offered, one must either abandon the assumption that respondents in experimental studies are optimizing, or make some assumptions

be correct. For instance, in field studies of electrical-appliance purchases, some subjects may have faced borrowing constraints that prevented them from choosing the more expensive energy-efficient appliances. More typically, however, imperfect capital markets cannot explain choices; they cannot explain why a person who holds several thousand dollars in a bank account earning 4-percent interest should prefer $100 today over $150 in one year. Because imputed discount rates do not, in fact, converge on the prevailing market interest rates, but are, instead, much higher, it seems that many respondents are neglecting capital markets and basing their choices on some other consideration, such as time preference or the uncertainty associated with delay.

6.1.3 *Concave Utility*

The standard approach to estimating discount rates assumes that the utility function is linear in the magnitude of the choice objects (e.g., amounts of money, pounds of corn, duration of some health state). If, instead, the utility function for the good in question is concave, estimates of time preference will be biased upward. For example, indifference between $100 this year and $200 next year implies a dollar discount rate of 100%. However, if the utility of acquiring $200 is less than twice the utility of acquiring $100, the utility discount rate will be less than 100%. This confound is rarely discussed, perhaps because utility is assumed to be approximately linear over the small amounts of money commonly used in time-preference studies. However, the overwhelming evidence for "reference-dependent" utility suggests that this assumption may be invalid — that people may not be integrating the stated amounts with their current and future wealth, and, therefore, that curvature in the utility function may be substantial even for these small amounts (see Ian Bateman, Alistair Munro, Bruce Rhodes, Chris Starmer, and Robert Sugden 1997; David W. Harless and Colin F. Camerer 1994; Kahneman and Tversky 1979; Rabin 2000; Rabin and Thaler 2001; Tversky and Kahneman 1991).

Three techniques could be used to avoid this confound. (1) One can request direct utility judgments (e.g., attractiveness ratings) of the same consequence at two different times, and then the ratio of the attractiveness rating of the distant outcome to the proximate outcome would directly reveal the implicit discount factor. However, regardless of how carefully one words the question, some respondents are likely to interpret it as asking them for the attractiveness of the

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(either implicit or explicit) about the nature of credit markets. The implicit assumption in some of the previous studies of discount rates appears to be that there are no possibilities for intertemporal arbitrage.…"

consequences at the time when they are experienced rather than the immediate attractiveness of the consequences, which would result in estimates of zero time preference even for people who did discount the future. (2) To the extent that utility is linear in probability, one can use choices or judgment tasks involving different probabilities of the same consequence at different times (Alvin E. Roth and J. Keith Murnighan 1982). But evidence that probability is weighted non-linearly (e.g., Starmer 2000) casts doubt on this approach. (3) One can separately elicit the utility function for the good in question, and then use that function to transform outcome amounts into utility amounts, from which utility discount rates could be computed. To our knowledge, Chapman (1996) conducted the only study that attempted to do this. She found that *utility* discount rates were substantially lower than the *dollar* discount rates, because utility was strongly concave over the monetary amounts subjects used in the intertemporal choice tasks. She also found that magnitude effects were much smaller after correcting for utility function curvature.[28]

6.1.4 Uncertainty

In experimental studies, subjects are typically instructed to assume that delayed rewards will be delivered with certainty. It is unclear whether subjects do (or can) accept this assumption, because delay is ordinarily — and perhaps unavoidably — associated with uncertainty. A similar problem arises for field studies, in which it is typically assumed that subjects believe future rewards, such as future energy savings, will materialize. Because of this subjective (or "epistemic") uncertainty associated with delay, it is difficult to disentangle to what extent the magnitude of imputed discount rates (or the shape of the discount function) is governed by time preference *per se*, and how much is attributable to the diminution in subjective probability associated with delay.[29]

Empirical evidence suggests that introducing objective (or "aleatory") uncertainty to both current and future rewards can dramatically affect estimated discount rates. For instance, Gideon Keren and Peter Roelofsema (1995) asked one group respondents to choose between 100 Florins

[28]This result supports Loewenstein and Prelec's (1992) explanation of magnitude effects (which we discussed in Section 5.2.2).

[29]There may be complicated interactions between risk and delay, because uncertainty about future receipt complicates and impedes the planning of one's future consumption stream (Michael Spence and Richard Zeckhauser 1972). For example, a 90% chance to win $10,000,000 in fifteen years is worth much less than a guarantee to receive $9,000,000 at that time, because, to the extent that the person cannot insure against the residual uncertainty, there is a limit to how much she can adjust her consumption level during those fifteen years.

immediately and 110 Florins in one month, and asked another group to choose between a 50-percent chance of 100 Florins immediately and a 50-percent chance of 110 Florins in one month. While 82 percent preferred the smaller immediate reward when both rewards were certain, only 39 percent preferred the smaller immediate reward when both rewards were uncertain.[30] Also, Albrecht and Weber (1996) found that the present value of a future lottery (e.g., a 50-percent chance of receiving 250 Deutchmarks) tended to exceed the present value of its certainty equivalent.

6.1.5 *Inflation*

The standard approach assumes that, for instance, $100 now and $100 in five years generate the same level of utility at the times they are received. A natural reason to devalue future monetary outcomes is inflation — because in the presence of inflation, $100 worth of consumption now is more valuable than $100 worth of consumption in five years. This confound creates an upward bias in estimates of the discount rate (of course, this bias will be more or less pronounced depending on the subjects' inflation experiences and expectations).

6.1.6 *Expectations of changing utility*

A second reason why $100 now might generate more contemporaneous utility than $100 in five years is that a person expects to have a larger baseline consumption level in five years (e.g., due to increased wealth). As a result, the marginal utility generated by an additional $100 of consumption in five years may be less than the marginal utility generated by an additional $100 of consumption now. Like inflation, this confound creates an upward bias in estimates of the discount rate.

6.1.7 *Habit formation, anticipatory utility, and visceral influences*

Finally, because the modifications to the instantaneous utility function discussed in Section 5 are usually ignored in empirical studies of the discount rate, they represent additional confounding factors. For instance, if a person wants an increasing consumption profile due to habit formation, then there will be a downward bias in estimates of the discount rate. Similarly, if

[30]This result cannot be explained by a magnitude effect on the expected amounts, because 50 percent of a reward has a *smaller* expected value, and, according to the magnitude effect, should be discounted more, not less.

future rewards create anticipatory utility, there will be an downward bias in estimates of the discount rate. Finally, if being offered an immediate reward stimulates visceral factors that increase the person's valuation of that reward, then there will be an upward bias in estimates of the discount rate.

6.1.8 *An illustrative example*

To illustrate how it can be difficult to separate out time preference, proper, from all these potential confounds, consider a prototypical study by Ben-Zion, Rapaport, and Yagil (1989). In this study, respondents equated immediate sums of money and larger delayed sums (e.g., they specified the reward in six months that would be as good as getting $1000 immediately). In the cover story for the questionnaire, respondents were asked to imagine that they had earned money (amounts ranged from $40 to $5000), but when they arrived to receive the payment they were told that the "financially solid" public institute is "temporarily short of funds." They were asked to specify a future amount of money (delays ranged from six months to four years) that would make them indifferent to the amount they had been promised to receive immediately. Surely, the description "financially solid" could scarcely be sufficient to allay uncertainties that the future reward would actually be received (particularly given that the institute had run out of funds, albeit temporarily), and it seems likely that responses included a substantial "risk premium." Moreover, the subjects in this study had "extensive experience with ... a three-digit inflation rate," and it therefore seems likely that respondents may have considered inflation when generating their responses. Even if respondents assumed no inflation, the real interest rate during this time was positive, and they might have considered intertemporal arbitrage. Finally, respondents may have considered that their future wealth would be greater and that the later reward would therefore yield less marginal utility. Indeed, the instructions cued respondents to this consideration, as they were told that the questions did not have correct answers, and that the answers "might vary from one individual to another depending on his or her present or future financial assets."

Given all of these confounding factors, is it unclear exactly how much of the imputed annual discount rates (which ranged from 9 percent to 60 percent) actually reflected time preference. It is possible that the responses in this study (and others) can be almost entirely explained in terms of these confounds, and that once these confounds are controlled for, very little "pure" time preference would remain.

6. 2 *Procedures for measuring discount rates*

We discussed above several confounding factors that greatly complicate the assignment of a discount rate to a particular choice or judgment. With these confounds in mind, we next discuss the methods that have been used to measure discount rates. Broadly, these methods can be divided into two categories: *field studies*, in which discount rates are inferred from economic decisions that people make in their ordinary life, and *experimental studies*, in which people are asked to evaluate stylized intertemporal prospects involving real or hypothetical outcomes. The different procedures are subject to the confounds discussed above, albeit to greater and lesser degrees, and, as we shall discuss, are also influenced by a variety of other factors that are theoretically irrelevant, but which can greatly affect the imputed rate of time preference.

6.2.1 *Field studies*

Some researchers have attempted to estimate discount rates by identifying "real world" behaviors that involve tradeoffs between the near and more distant future. Early studies of this type examined consumers' choices among different models of electrical appliances, which often present purchasers with a tradeoff between the immediate purchase price and the long-term costs of running the appliance (as determined by its energy efficiency). In these studies, the discount rates implied by consumers' choices vastly exceeded market interest rates, and differed substantially across product categories. The implicit discount rate was 17-20 percent for air conditioners (Jerry Hausman 1979); 102 percent for gas water heaters, 138 percent for freezers, and 243 percent for electric water heaters (H. Ruderman, M. D. Levine, and J. E. McMahon 1987); and from 45 percent to 300 percent for refrigerators, depending on assumptions made about the cost of electricity (D. Gately 1980).[31]

Another set of studies impute discount rates from wage-risk tradeoffs, in which individuals

[31]These findings illustrate how people seem to ignore intertemporal arbitrage. As Hausman (1979) noted, it does not make sense for anyone with positive savings to discount future energy savings at rates higher than the market interest rate. One possible explanation for these results is that people are liquidity constrained. Consistent with such an account, Hausman found that the discount rate varied markedly with income — it was 39 percent for households with under $10,000 of income, but just to 8.9 percent for households earning between $25,000 and $35,000. However, conflicting with this finding, a study by Douglas Houston (1983) which presented individuals with a decision of whether to purchase a hypothetical "energy saving" device, found that income "played no statistically significant role in explaining the level of discount rate."

decide whether to accept a riskier job with a higher salary. Such decisions involve a tradeoff between quality of life and expected length of life. The more that future utility is discounted, the less important is length of life, and hence the more attractive are risky but high-paying jobs. From such tradeoffs, W. Kip Viscusi and Michael Moore (1989) concluded that workers' implicit discount rate with respect to future life years was approximately 11 percent. Later, using different econometric approaches with the same data set, Moore and Viscusi (1990a) estimated the discount rates to be around 2 percent, and Moore and Viscusi (1990b) concluded that the discount rate was somewhere between 1 percent and 14 percent. Mark Dreyfus and Viscusi (1995) applied a similar approach to auto-safety decisions and estimated discount rates ranging from 11 percent to 17 percent.

In the macroeconomics literature, researchers have imputed discount rates by estimating structural models of life-cycle saving behavior. For instance, Emily Lawrence (1991) estimated Euler equations to identify time-preference parameters. While her main focus was how household time preference differed across different socioeconomic groups, she reported point estimates for the discount rate of median-income households of between 4 percent and 13 percent depending on the specification. Christopher Carroll (1997) criticizes Euler-equation estimation on the grounds that most households tend to engage mainly in “buffer-stock” saving early in their lives — they save primarily to be prepared for emergencies — and only conduct “retirement” saving later on. Recent papers have estimated rich, calibrated, stochastic models in which households conduct buffer-stock saving early in life and retirement saving later in life. Using this approach, Carroll and Andrew Samwick (1997) report point estimates for the discount rate ranging from 5 percent to 14 percent, and Pierre-Olivier Gourinchas and Jonathan Parker (2001) report point estimates of 4.0-4.5 percent. Field studies of this type have the advantage of not assuming isolation, because integrated decision making is built into the model. But such estimates often depend heavily on myriad assumptions needed to close the structural model.

Recently, John Warner and Saul Pleeter (2001) analyzed decisions made by United States military servicemen. As part of military downsizing, over 60,000 military employees were given the choice between a one-time, lump-sum payment and an annuity payment. The sizes of the payments depended on the employee's current salary and number of years of service — e.g., an “E-5” with nine years of service could choose between $22,283 now vs. $3,714 every year for 18 years. In general, the present value of the annuity payment equaled the lump-sum payment for a

discount rate of 17.5 percent. Although the interest rate was only 7 percent at the time of these decisions, over half of all military officers and over 90 percent of enlisted personnel chose the lump sum payment.[32] This study is particularly compelling in terms of credibility of reward delivery, magnitude of stakes, and number of subjects.[33]

The benefit of field studies, as compared with experimental studies, is their high *ecological* validity. There is no concern about whether estimated discount rates would apply to "real" behavior because they are estimated from such behavior. But field studies are subject to additional confounds due to the complexity of real-world decisions and the inability to control for some important factors. For example, the high discount rates implied by the widespread use of inefficient electrical appliances might not result from the discounting of future cost savings per se, but from other considerations, including: (1) a lack of information among consumers about the cost savings of the more efficient appliances; (2) a disbelief among consumers that the cost savings will be as great as promised; (3) a lack of expertise in translating available information into economically efficient decisions; or (4) “hidden costs” of the more efficient appliances, such as reduced convenience or reliability, or, in the case of light bulbs, because the more efficient bulbs generate a less aesthetically pleasing light spectra.[34]

6.2.2 *Experimental studies*

Given the difficulties of interpreting field data, the most common methodology for eliciting discount rates is to solicit “paper-and-pencil” responses to the prospect of real and hypothetical rewards and penalties. Four experimental procedures are commonly used: choice tasks, matching tasks, pricing tasks, and ratings tasks.

Choice tasks are the most common experimental method for eliciting discount rates. In a typical choice task, subjects are asked to choose between a smaller, more immediate reward and a larger, more delayed reward. Of course, a single choice between two intertemporal options only reveals an upper or lower bound on the discount rate — for example, if a person prefers 100 units

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[32]It should be noted, however, that the guaranteed payments in the annuity program were not indexed for inflation, which averaged 4.2 percent during the four years preceding this choice.

[33]Warner and Pleeter (2001) noted that if everyone had chosen the annuity payment, the present value of all payments would have been $4.2 billion. Given the choices however, the present value of the government payout was just 2.5 billion. Thus, offering the lump-sum alternative saved the federal government $1.7 billion dollars.

[34]However, for a criticism of the “hidden costs” explanation, see Jonathan Koomey and Alan Sanstad (1994) and Richard Howarth and Sanstad (1995).

of something today over 120 units a year from today, the choice merely implies a discount rate of *at least* 20 percent per year. To identify the discount rate more precisely, researchers often present subjects with a series of choices that vary the delay or the amount of the rewards. Some studies use real rewards, including money, rice, and corn. Other studies use hypothetical rewards, including monetary gains and losses, and more or less satisfying jobs available at different times. (See Table 2 for a list of the procedures and rewards used in the different studies.)

Like all experimental elicitation procedures, the results from choice tasks can be affected by procedural nuances. A prevalent problem is an "anchoring effect": When respondents are asked to make multiple choices between immediate and delayed rewards, the first choice often influences subsequent ones. For instance, people would be more prone to choose $120 next year over $100 immediately if they first chose between $100 immediately vs. $103 next year than if they first chose between $100 immediately vs. $140 next year. In general, imputed discount rates tend to be biased in the direction of the discount rate that would equate the first pair of options to which they are exposed (see Donald Green, Karen Jacowitz, Kahneman, and Daniel McFadden 1998). Anchoring effects can be minimized by using "titration" procedures which expose respondents to a series of opposing anchors (e.g., (1) $100 today or $101 in one year?, (2) $100 today or $10,000 in one year?, (3) $100 today or $105 in one year? …and so on.). However, because titration procedures typically only offer choices between an immediate reward and a *smaller* future reward, even these procedures communicate to respondents that they should be discounting, and potentially bias discount rates upward.

Matching tasks are another popular method for eliciting discount rates. In matching tasks, respondents "fill in the blank" to equate two intertemporal options (e.g., $100 now = $____ in one year). Matching tasks have been conducted with real and hypothetical monetary outcomes and with hypothetical aversive health conditions (again see Table 2 for a list of the procedures and rewards used in different studies). Matching tasks have two advantages over choice tasks. First, because subjects reveal an indifference point, an exact discount rate can be imputed from a single response. Second, because the intertemporal options are not fully specified, there is no anchoring problem and no suggestion of an expected discount rate (or range of discount rates). Thus unlike choice tasks, matching tasks cannot be accused of simply recovering the expectations of the experimenters that guided the experimental design.

Although matching tasks have some advantages over choice tasks, there are reasons to be

suspect of the responses obtained. First, responses often appear to be governed by the application of some simple rule rather than by time preference. For example, when people are asked to state the amount in n years that equals $100 today, a very common response is $100*n. Second, the responses are often very "coarse" — often multiples of 2 or 10 of the immediate reward, suggesting that respondents do not (or cannot) think very carefully about the task. Third, and most importantly, there are large differences in imputed discount rates among several theoretically equivalent procedures. Two intertemporal options could be equated or "matched" in one of four ways: Respondents could be asked to specify (1) the amount of a delayed reward that would make it as attractive as a given immediate reward (which is the most common technique); (2) the amount of an immediate reward that makes it as attractive as a given delayed reward (Albrecht and Weber 1996); (3) the maximum length of time they would be willing to wait to receive a larger reward in lieu of an immediately available smaller reward (Ainslie and Haendel 1983; Roelofsema 1994); or (4) the latest date at which they would accept a smaller reward in lieu of receiving a larger, reward at a specified later date.

While there is no theoretical basis for preferring one of these methods over any other, the small amount of empirical evidence comparing different methods suggests that they yield very different discount rates. Roelofsema (1994) found that implicit discount rates varied tremendously depending on whether respondents matched on amount or time. One group of subjects was asked to indicate how much compensation they would demand to allow a purchased bicycle to be delivered 9 months late. The median response was 250 florins (a Netherlands unit of currency). Another group was asked how long they would be willing to delay delivery of the bicycle in exchange for 250 florins. The mean response was only 3 weeks, implying a discount rate that is twelve times higher. Frederick (2000) found that implicit discount rates were dramatically higher when respondents generated the future reward that would equal a specified current reward than when they generated a current reward that would equal a specified future reward. Specifically, when respondents were asked to state the amount in 30 years that would be as good as getting $100 today, the median response was $10,000 (implying that a future dollar is $1/100^{th}$ as valuable), but when asked to specify the amount today that is as good as getting $100 in thirty years, the median response was $50 (implying that a future dollar is ½as valuable).

Two other experimental procedures involve rating or pricing temporal prospects. In *rating tasks*, each respondent evaluates an outcome occurring at a particular time by rating its

attractiveness or aversiveness. In *pricing tasks*, each respondent specifies a willingness to pay to obtain (or avoid) some real or hypothetical outcome occurring at a particular time, such as a monetary reward, dinner coupons, an electric shock, or an extra year added to the end of one's life. (Once again, see Table 2 for a list of the procedures and rewards used in the different studies.) Rating and pricing tasks differ from choice and matching tasks in one important respect. Choice and matching tasks both call attention to time because each respondent evaluates two outcomes occurring at two different times. Rating and pricing tasks, in contrast, permit time to be manipulated *between subjects*, because a single respondent may evaluate either the immediate or delayed outcome, by itself.

Loewenstein (1988) found that the timing of an outcome is much less important (discount rates are much lower) when respondents evaluate a single outcome at a particular time than when they compare two outcomes occurring at different times, or specify the value of delay or acceleration of an outcome. In one study, for example, two groups of students were asked how much they would pay for a $100 gift certificate at the restaurant of their choice. One group was told that the gift certificate was valid immediately. The other was told it could be used beginning 6 months from now. There was no significant difference in the valuation of the two certificates *between* the two groups, which implies negligible discounting. However, when asked how much they would pay [have to be paid] to use it 6 months earlier [later], the timing became important — the "delay" group was willing to pay $10 to expedite receipt of the delayed certificate and the "immediate" group demanded $23 to delay the receipt of a certificate they expected to be able to use immediately.[35]

Another important design choice in experimental studies is whether to use real or hypothetical rewards. The use of real rewards is generally desirable for obvious reasons, but hypothetical rewards actually have some advantages in this domain. In studies involving hypothetical rewards, respondents can be presented with a wide range of reward amounts, including losses and large gains, both of which are generally infeasible in studies involving real outcomes. The disadvantage of hypothetical choice data is the uncertainty about whether people are motivated to, or capable of, accurately predicting what they would do if outcomes were

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[35] Rating tasks (and probably also pricing tasks) are subject to anchoring effects. Shelley and Thomas Omer (1996), Mary Kay Stevenson (1992), and others have found that a given delay (e.g., 6 months) produces greater time discounting when it is considered alongside shorter delays (e.g., 1 month) than when it is considered alongside longer delays (e.g., 3 years).

real.To our knowledge, Kirby and Marakovic (1995) is the only study that compared discounting between real and hypothetical rewards.[36] They asked subjects to state the immediate amount that would make them indifferent to some fixed delayed amount (delayed reward sizes were $14.75, $17.25, $21.00, $24.50, $28.50; delays were 3, 7, 13, 17, 23, and 29 days). One group of subjects answered all 30 permutations for real rewards, and another group of subjects answered all 30 permutations for hypothetical rewards. Discount rates were *lower* for hypothetical rewards, which contradicts the possible explanation that seemingly too high discount rates are driven by the hypothetical nature of many studies.[37]

6.3 *Conclusion: What is time preference?*

Figure 2 reveals spectacular disagreement among dozens of studies that all purport to be measuring time preference. This lack of agreement likely reflects the fact that the various elicitation procedures used to measure time preference consistently fail to isolate time preference, and instead reflect, to varying degrees, a blend of both pure time preference and other theoretically distinct considerations, including: (a) intertemporal arbitrage, when tradeable rewards are used; (b) concave utility; (c) uncertainty that the future reward or penalty will actually obtain; (d) inflation, when nominal monetary amounts are used; (e) expectations of changing utility; and (f) considerations of habit formation, anticipatory utility, or visceral influences.

Figure 2 also reveals a predominance of high implicit discount rates — discount rates well above market interest rates. This consistent finding may also be due to the presence of the various "extra-time-preference" considerations listed above, because nearly all of these work to bias estimates upward — only habit formation and anticipatory utility bias estimates downward. If these confounding factors were adequately controlled, we suspect that many intertemporal choices or judgments would be seen as consistent with much lower rates of time preference.

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[36]There has been considerable recent debate outside of the context of intertemporal choice about whether hypothetical choices are representative of decisions with real consequences. The general conclusion from this debate is that the two methods typically yield qualitatively similar results (see Camerer and Robin Hogarth 1999 for a recent review), though systematic differences have been observed in some studies (Ronald Cummings, Glenn Harrison and Elisabet Rutstrom 1995; Yoram Kroll, Haim Levy and Rapoport 1988).

[37] The two results were not strictly comparable, however, because they used a different procedure for the real rewards than for the hypothetical rewards. An auction procedure was used for the real-rewards group only. Subjects were told that whoever, of three subjects, stated the lowest immediate amount would receive the immediate amount, and the other two subjects would receive the delayed amount. Optimal behavior in such a situation involves over-bidding. However, since this creates a downward bias in discount rates for the real-rewards group, it does not explain away the finding that real discount rates were higher than hypothetical discount rates.

Our discussion in this section highlights the conceptual and semantic ambiguity about what the concept of "time preference" ought to include. Just as psychologists debate whether social affability, sense of humor, and musical talent ought to be regarded as components of "intelligence," there may be disagreement about what properly counts as time preference *per se* and what ought to be called something else. We have argued here that many of the reasons for caring when something occurs (e.g., uncertainty or utility of anticipation) are not time preference, because they pertain to the expected amount of utility consequences confer, and not to how the utility of different moments is weighted (see left-hand side of Figure 3). However, it is not obvious where to draw the line between factors that operate through utilities and factors that make up time preference. For example, suppose someone sacrifices a fraction of an attractive future reward to obtain it sooner. Such behavior surely meets the classic definition of "impatience." We could, however, disqualify this behavior as an expression of time preference by invoking some aspect of the utility function to explain it (e.g., that the person is merely alleviating the distress they experience while waiting for rewards).

Hopefully, economists will eventually achieve a consensus about what is included in, and excluded from, the concept of time preference. In the meantime, drawing attention to the ambiguity of the concept will hopefully improve the quality of discourse by increasing awareness that, in discussions about time preference, different people may be using the same term to refer to significantly different underlying constructs.

7. *Unpacking Time Preference*

As detailed in Section 2, early 20th century economists' conceptions of intertemporal choice included detailed accounts of disparate underlying psychological motives. With the advent of the DU model in 1937, however, economists eschewed considerations of specific motives, proceeding as if all intertemporal behavior could be explained by the unitary construct of "time preference." In Sections 5 and 6, we highlighted several factors that influence intertemporal decisions but would not be considered time preference as the term is ordinarily used. In this section, we turn our focus inward and question whether even time preference itself should be appropriately considered as a unitary construct.

Issues of this type are hotly debated in psychology. For example, psychologists debate the

usefulness of conceptualizing intelligence in terms of a single unitary "g" factor. The key to a construct of this type — a "trait" in psychological parlance — being useful is that it must (1) differ across persons but remain relatively constant within the same person over time, and (2) predict behavior in a wide range of situations. Intelligence fits these criteria, though debates remain about whether traditional measures fail to include important dimensions, and about whether a multidimensional account of intelligence would have even greater explanatory power.[38] Other psychological constructs have fallen short of satisfying these twin criteria. For example, psychologists in the 1950s proposed that people could be described as more or less "authoritarian." But subsequent research has shown that scales intended to measure authoritarianism are neither stable across time nor predictive across situations (John L. Martin 2001), which calls into question the value of the underlying construct.[39]

How does time preference fare by these twin criteria? The answer is at best mixed. On the positive side, Mischel and his colleagues have observed statistically significant correlations between propensity to delay gratification in children around 4 years of age and a range of subsequent lifetime behaviors and experiences, including higher academic achievements and social and cognitive competencies, higher self-esteem, and effective goal pursuit assessed over the course of many decades (Ozlem Ayduk, Rodolfo Mendoza-Denton, Mischel, G. Downey, Philip K. Peake, and Monica Rodriguez 2000; Mischel, Yuichi Shoda, and Peake 1988; Shoda, Mischel, and Peake 1990). It has also been found that drug addicts discount the future – both money and drugs – more steeply than non-addicts (e.g., Leanne Alvos, R.A. Gregson, & Michael Ross, 1993; Kris Kirby, Nancy Petry and Warren Bickel 1999; Thomas Murphy and Alan De Wolfe, 1986; Petry, Bickel, and Martha Arnett 1998), though it is unclear whether high discounting contributes to addiction or the reverse (or both). Indeed, consistent with the idea that addiction contributes to steep time discounting, recent research shows that when addicts are in a craving state, they discount both drugs and money more steeply than when they are not craving (Louis Giordano, Bickel, Loewenstein, Eric Jacobs, Lisa Marsch, and Gary Badger, 2001).)

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[38]Robert Sternberg (1985), for example, argues that intelligence is usefully decomposed into three dimensions: (1) analytical intelligence, which includes the ability to identify problems, compute strategies, and monitor solutions, and is measured well by existing IQ tests; (2) creative intelligence, which reflects the ability to generate problem-solving options, and (3) practical intelligence, which involves the ability to implement problem-solving options. He argues that different types of tasks are facilitated by different types of intelligence.

[39]In a testament to the tenacity of flawed ideas, however, the construct continues to be referred to and used in research.

On the negative side, Chapman and Elstein (1995) found only weak (0.26) correlations between pairs of questions intended to measure discount rates for money and health, and almost no correlation between discount rates imputed from choices between losses and those imputed from choices between gains.[40] John Cairns (1992) estimated generally low consistency in discount rates derived from hypothetical choices involving expediting or delaying money receipts and payments, and expediting or delaying negative health states. Fuchs (1982), in a survey of 508 Long Island residents, found little correlation between items intended to measure discount rates for money — e.g., "Would you choose $1500 now or $4000 in five years?" Reflecting negatively on the second criterion — the ability of discount rates to predict behavior across diverse domains — Fuchs also observed no substantial correlations between temporally related behavioral items, such as their use of credit cards, their tendency to use debt to buy a car, the frequency with which they exercised, and how much they smoked, nor between these items and the choices among immediate and delayed monetary rewards (see also E. K. Nyhus 1995).It is difficult to know what to make of the lack of cross-activity consistency. To the extent that motives other than time discounting (such as subjective expectations about the likelihood of outcomes) are important, and affect different people differently, one would not expect to observe a high degree of consistency across intertemporal choices even if people did, in fact, have a unitary rate of time preference that they applied to the utility of all activities. Suppose, for example, that a person typically chose the larger future monetary rewards over smaller immediate ones, but then indicated that they rarely exercised. Perhaps the person gets so little exercise *because* he is so busy at work earning money for his future. Due to such "noise," one cannot definitively interpret the lack of strong cross-activity correlations in behavior as evidence against a single discount rate. The lack of consistency in discount rates measured from choices between monetary prospects provides somewhat stronger evidence against the existence of a stable unitary rate of time preference.

To fully explain all these inconsistencies, and to fully understand intertemporal choice, we may need to unpack time preference itself into more basic motives (as illustrated by the right-hand side of Figure 3). In fact, there is at least initial and speculative evidence that decomposing time preference into appropriate subcomponents may yield dividends in terms of explanation and prediction. Loewenstein, Roberto Weber, Janine Flory, Stephen Manuck and Matthew Muldoon

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[40] A similar lack of *intraindividual* consistency has been observed in risk-taking (Kenneth Kenneth MacCrimmon and Donald Wehrung 1990).

(2001) have been engaged in an extended research project to examine the dimensionality of time preference. In an initial survey, they administered a number of multi-item psychometric scales designed to measure various aspects of time preference to a convenience sample of several hundred Pittsburgh adults. They used factor analysis to identify clusters of items highly correlated with one-another but not with items in other clusters. In two subsequent surveys, they refined the subscales. This process resulted in a scale comprising three separate subscales which they labeled "impulsivity," "compulsivity," and "inhibition."

Impulsivity, as measured by the items in the scale, reflects the degree to which an individual acts in a spontaneous, unplanned fashion. The impulsivity subscale includes 6 items, such as "sometimes I do things on impulse that I later regret," and "occasionally I act first and think later." Compulsivity refers to the tendency to make plans and stick with them. This subscale includes 8 items, such as "I never seem to be able to get organized" (coded negatively) and "I'm pretty good about pacing myself so as to get things done on time." Behavioral inhibition refers to the ability to inhibit the natural/automatic response to the appetites, emotions and so on that often trigger impulsive behavior. The subscale measuring inhibition includes eight items such as "I control my behavior," and "It takes a lot to get me mad."[41]

To test the efficacy of breaking time preference into these subcomponents, they conducted a final study in which they administered the three subscales along with a series of questions that measured monetary discount rates, and a large battery of questions about time-related behaviors to a convenience sample of 269 Pittsburgh adults. Consistent with the existence of quasi-independent attributes underlying intertemporal choice behavior, items intended to measure each construct correlated strongly with each other, but less well with items intended to measure different constructs. In fact, in a factor analysis of all of the subscales, the individual items clustered into exactly the same three dimensions that they had in earlier surveys. Moreover, different subdimensions predicted different behaviors in a highly sensible way. Thus, for example, repetitive behaviors such as flossing one's teeth, exercising, paying one's bills on time, and arriving on time at meetings, were all predicted best by the compulsivity subdimension. Viscerally-driven behaviors, such as reacting aggressively to someone in a car who honks at you at a red light, were

[41]Recent research by Baumeister and colleagues (Roy Baumeister, Todd Heatherton and Diane Tice, 1994) suggests that such "behavioral inhibition" requires an expenditure of mental effort that, like other forms of effort, draws on limited resources — e.g., a "pool" of willpower (Loewenstein 2000a). Their research shows that exercising behavioral inhibition in one domain — e.g., refraining from eating desirable food — leads to decreased

best predicted by impulsivity (positively) and behavioral inhibition (negatively). Money-related behaviors such as saving money, having unpaid credit card balances or being maxed out on one or more credit cards, were best predicted by estimated discount rates (although impulsivity and compulsivity were also both highly significant predictors). Although not all statistical relationships came out as predicted, large numbers did, and the overall pattern was intuitively sensible. Overall, the analysis supports the idea that different subdimensions of time preference can be measured reliably and that these subdimensions contribute differentially to the prediction of different types of behaviors.

Clearly, further research is needed to ascertain whether time discounting is best viewed as a unitary construct or a composite of more basic motives. Moreover, even if the multiple-motive view ends up being supported empirically, it will inevitably be more difficult to operationalize than formulations, such as the DU model, which assume the existence of a monodimensional rate of time preference. Thus, the benefits of the multiple-motive approach may not be worth the cost of the additional complexity. However, if it does turn out to be the case that some behaviors are best predicted by impulsivity, some by compulsivity, some by behavioral inhibition, and so on, it may well be worth the effort to measure preferences at this level and to develop models that incorporate these dimensions of preference.

8. *Conclusions*

In this paper, we have attempted to introduce the reader to the "state of the art" in the area of intertemporal choice. Not surprisingly, given that we are behavioral economists, our view of the state of the art is heavily informed by research in psychology and behavioral economics. The research that we have discussed highlights several primary themes:

(1) The DU model, which continues to be widely used by economists, has little empirical support. Even its developers — Samuelson, who originally proposed the model, and Koopmans, who provided the first axiomatic derivation — had concerns about its descriptive realism, and it was never empirically validated as the appropriate model for intertemporal choice. Quite the opposite, recent empirical evidence has called into question virtually all of the DU model's core

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exercise of inhibition in other domains — e.g., less persistence on mental or physical tasks.

and ancillary assumptions.

(2) Significant strides have been made in developing new theories of intertemporal choice that incorporate the insights from recent empirical research. These theories have revived many of the psychological considerations discussed by early students of intertemporal choice, such as Jevons, Senior, Böhm-Bawerk, and Fisher, considerations that were dismissed with the introduction of the DU model. Moreover, many of these alternative theories achieve far greater descriptive validity than the DU model without adding much additional complexity.

(3) People's understanding of their temporal preferences (their "metaknowledge") can often have dramatic consequences for intertemporal choice. As highlighted by the work of O'Donoghue and Rabin, the effects of self-control problems, such as procrastination, are amplified when people underestimate their vulnerability to the problem. Similarly, the types of misprediction of future preferences that fit the pattern that Loewenstein, O'Donoghue and Rabin (2000) call "projection bias" can contribute to a wide range of bad intertemporal decisions. If, for example, a person underpredicts her own vulnerability to addiction, she will be too likely to enjoy the short-term pleasures of drugs at the expense of the long-term costs associated with addiction.

(4) While the DU model assumes that people are characterized by a single discount rate, a large empirical literature has attempted to estimate discount rates, and has failed to identify any robust estimates of discount rates across studies (and sometimes even within studies). This failure is partly due to invalid assumptions (e.g., that choices are made in isolation, that utility is linear in amount; or that people are certain about the receipt of future rewards). But this failure is also attributable to the fact that there are many motives behind intertemporal choices, and these empirical studies condense all these motives into a single discount rate. To the extent that psychology and behavioral economics helps economists to develop richer, more realistic models of intertemporal choice, it should also help to achieve a better empirical estimates of the motives behind intertemporal choices.

The theme of multiple motives extends throughout our paper. Section 2 details how early 20^{th} century economists' conceptions of intertemporal choice included detailed accounts of the disparate psychological motives underlying intertemporal choice. The limitations of the DU model discussed in Section 4, and the estimation problems discussed in Section 6, can be interpreted as manifestations of the failure to take account of specific motives such as the desire

for improvement, utility from anticipation, habit formation, and visceral influences. Many of the new theories introduced in Section 5 can be viewed as attempts to incorporate such motives. And Section 7 describes how it may be useful to unpack time preference itself into several more basic motives.

What is value of re-introducing the multiple motives behind intertemporal choice? The most obvious advantages are to achieve better descriptive realism in explaining the intertemporal choices we observe in the world and to conduct better informed policy analysis. But in addition, the multiple-motive approach to intertemporal choice may help us better understand both inter-individual and *intra*-individual heterogeneity.

People behave differently — one person might be a spendthrift while his neighbor is a miser; one person might be a casual drinker while another person drinks heavily whenever alcohol is present. When viewed from the perspective of the DU model, such inter-individual differences can be explained only by people having different discount rates, different constraints, or different tastes for the good in question. With the multiple-motive approach, there is more scope for understanding such differences, because people may differ in the degree to which they experience anticipatory utility, or are influenced by visceral factors, or are able to correctly predict their future utility.

The multiple-motive approach may be even more important for understanding *intra*-individual differences, and related more complicated inter-individual differences. When one looks at the behavior of a single individual across different domains, there is often a wide range of apparent attitudes toward the future. The same person who smokes saves for retirement; people devote the early part of their lives establishing a career, and then jeopardize these investments to gain highly transient pleasures; and people squirrel money away in low-interest saving accounts while, at the same time, not paying off their credit cards. Such intra-individual heterogeneity can give rise to seemingly puzzling inter-individual heterogeneity — e.g., one person might save but not exercise, while another person might exercise but not save. Within the DU model, an individual discounts utilities from all outcomes at the same constant rate, and hence intra-individual heterogeneities can be understood only in terms of different constraints or different tastes across the different domains. But the multiple-motive approach allows us to interpret such differences in terms of the specific motives for the person. The smoker who saves might be a relatively patient person who is heavily influenced by the visceral elements of smoking.

Although the multiple-motive approach sounds potentially valuable, the reader may fear it is excessively open-ended. We have described a variety of considerations that people might incorporate into their analyses. Incorporating every consideration would be far too complicated, while at the same time, picking and choosing which considerations to incorporate may leave one open to charges of being *ad hoc*. How, then, should economists proceed?

We would argue that economists should proceed exactly they have always proceeded. Economic modeling has always been both a science and an art. Economists are forced to intuit, to the best of their abilities, which considerations are likely to play a prominent role in a particular domain, and which considerations are likely to be largely irrelevant. When economists model labor supply, they typically do so with a utility function that incorporates consumption and leisure, but when they model investment decisions, they typically assume that preferences are defined over wealth. For each domain, they choose the utility function that is best able to incorporate the essential considerations for that domain. Similarly, a researcher investigating charitable giving might use a utility function that incorporates altruism but not risk aversion or time preference, whereas someone studying investor behavior is unlikely to use a utility function that incorporates altruism. The same approach can be applied to multiple-motive models of intertemporal choice. In some cases, such as drug addiction, habit formation, visceral factors, and perhaps hyperbolic discounting seem likely to play a prominent role. For extended experiences, such as extended health states, careers, and long vacations, the preference for improvement is likely to come into play. For brief, vivid positive and negative outcomes, such as weddings or criminal sanctions, on the other hand, utility from anticipation may be an important determinant of behavior.

Moreover, economists can also *assess* their modeling decisions just as they always do: by finding empirical evidence that the specific considerations included do indeed play an important role, and by conducting robustness checks. But with regard to the former, economists should be receptive to a different type of empirical test: Rather than only testing the implications of an assumption, as we typically do, we should also consider direct tests of the assumption itself. Furthermore, new sources of data should be exploited. For instance, the dramatic cross-national and cross-cultural differences in intertemporal-choice behavior — e.g., differences in savings rates — that drew the attention and speculation of early scholars such as Rae have been largely ignored by modern researchers. In addition, economists should begin to draw on the data being generated by neuroscience. For example, neuroscientists have identified brain regions in which neural

damage (typically caused by strokes or auto accidents) causes extreme myopia (Antonio R. Damasio 1994). Other researchers have located brain regions that either translate the perception of a stimulus directly into behavior (e.g., fleeing when frightened) or suppress that prepotent behavioral response (Joseph E. LeDoux 1996). Economists may be able to use this data to assess and improve our assumptions about intertemporal decision making.

In sum, economists' continued progress on intertemporal choice will be greatly facilitated by informing modeling and methodological tools with insights from psychology. We hope that this paper will help to promote such a synthesis.

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Table 1
Determinants of Time Preference
(and main proponents)

uncertainty of human life	Rae
passion to partake immediate pleasures	Rae
bequest motive	Rae
propensity to exercise self restraint	Rae
pleasures of anticipation	Jevons
pain of deferral	Senior
underestimation of future wants	Böhm-Bawerk, Pigou
fashion	Fisher

Table 2

Empirical estimates of discount rates

STUDY	TYPE	GOOD(S)	REAL or HYPO?	Elicitation Method	TIME RANGE	Annual Discount rate(s)	δ
Maital & Maital (1978)	Experimental	money & coupons	hypo	Choice	1 year	70%	0.59
Hausman (1979)	Field	money	real	Choice	undefined	5% to 89%	0.95 to 0.53
Gateley (1980)	Field	money	real	Choice	undefined	45% to 300%	0.69 to 0.25
Thaler (1981)	Experimental	money	hypo	Matching	3 months to 10 years	7% to 345%	0.93 to 0.22
Ainslie & Haendel (1983)	Experimental	money	real	Matching	undefined	96000% to ∞	0.00
Houston (1983)	Experimental	money	hypo	Other	1 year to 20 years	23%	0.81
Loewenstein (1987)	Experimental	money & pain	hypo	Pricing	immediately to 10 years	-6% to 212%	1.06 to 0.32
Moore and Viscusi (1988)	Field	life years	real	Choice	undefined	10% to 12%	0.91 to 0.89
Benzion et al. (1989)	Experimental	money	hypo	Matching	6 months to 4 years	9% to 60%	0.92 to 0.63
Viscusi & Moore (1989)	Field	life years	real	Choice	undefined	11%	0.90
Moore & Viscusi (1990a)	Field	life years	real	Choice	undefined	2%	0.98
Moore & Viscusi (1990b)	Field	life years	real	Choice	undefined	1% to 14%	0.99 to 0.88
Shelley (1993)	Experimental	money	hypo	Matching	6 months to 4 years	8% to 27%	0.93 to 0.79
Redelmeier & Heller (1993)	Experimental	health	hypo	Rating	1 day to 10 years	0%	1.00
Cairns (1994)	Experimental	money	hypo	Choice	5 years to 20 years	14% to 25%	0.88 to 0.80
Shelley (1994)	Experimental	money	hypo	Rating	6 months to 2 years	4% to 22%	0.96 to 0.82
Chapman & Elstein (1995)	Experimental	money & health	hypo	Matching	6 months to 12 years	11% to 263%	0.90 to 0.28
Dolan & Gudex (1995)	Experimental	health	hypo	Other	1 month to 10 years	0%	1.00
Dreyfus and Viscusi (1995)	Field	life years	real	Choice	undefined	11% to 17%	0.90 to 0.85

Kirby & Marakovic (1995)	Experimental	money	real	Matching	3 days to 29 days	3678% to ∞	0.03 to 0.00
Chapman (1996)	Experimental	money & health	hypo	Matching	1 year to 12 years	negative to 300%	1.01 to 0.25
Kirby & Marakovic (1996)	Experimental	money	real	Choice	6 hours to 70 days	500% to 1500%	0.17 to 0.06
Pender (1996)	Experimental	rice	real	Choice	7 months to 2 years	26% to 69%	0.79 to 0.59
Wahlund & Gunnarson (1996)	Experimental	money	hypo	Matching	1 month to 1 year	18% to 158%	0.85 to 0.39
Cairns & Van der Pol (1997)	Experimental	money	hypo	Matching	2 years to 19 years	13% to 31%	0.88 to 0.76
Green, Myerson, & McFadden (1997)	Experimental	monay	hypo	Choice	3 months to 20 years	6% to 111%	0.94 to 0.47
Johanneson & Johansson (1997)	Experimental	life years	hypo	Pricing	6 years 57 years	0% to 3%	0.97
Kirby (1997)	Experimental	money	real	Pricing	1 day to 1 month	159% to 5747%	0.39 to 0.02
Madden et al. (1997)	Experimental	money & heroin	hypo	Choice	1 week to 25 years	8% to ∞	0.93 to 0.00
Chapman & Winquist (1998)	Experimental	money	hypo	Matching	3 months	426% to 2189%	0.19 to 0.04
Holden, Shiferaw, & Wik (1998)	Experimental	money & corn	real	Matching	1 year	28% to 147%	0.78 to 0.40
Cairns & Van der Pol (1999)	Experimental	health	hypo	Matching	4 years to 16 years	6%	0.94
Chapman, Nelson, & Hier (1999)	Experimental	money & health	hypo	Choice	1 month to 6 months	13% to 19000%	0.88 to 0.01
Kirby, Petry, & Bickel (1999)	Experimental	money	real	Choice	7 days to 186 days	50% to 55700%	0.67 to 0.00
Van Der Pol & Cairns (1999)	Experimental	health	hypo	Choice	5 years to 13 years	7%	0.93
Chesson & Viscusi (2000)	Experimental	money	hypo	Matching	1 year to 25 years	11%	0.90
Ganiats et al. (2000)	Experimental	health	hypo	Choice	6 months to 20 years	negative to 116%	1.01 to 0.46
Hesketh (2000)	Experimental	money	hypo	Choice	6 months to 4 years	4% to 36%	0.96 to 0.74
Van Der Pol & Cairns (2001)	Experimental	health	hypo	Choice	2 years to 15 years	6% to 9%	0.94 to 0.92
Warner & Pleeter (2001)	Field	money	real	Choice	Undefined	0% to 30%	1.00 to 0.77

Figure 1
Discount rates estimated from different studies

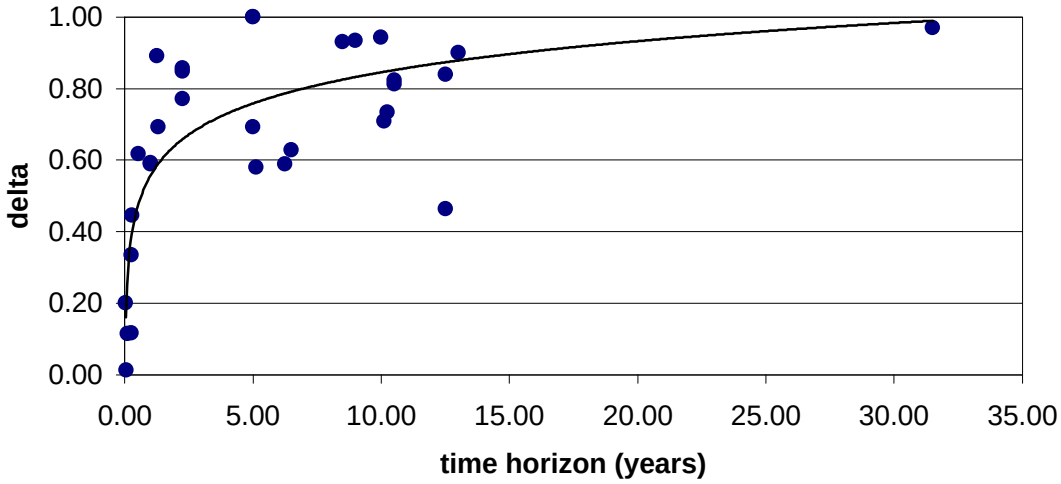


Figure 2
Discount Rates by Year of Study Publication

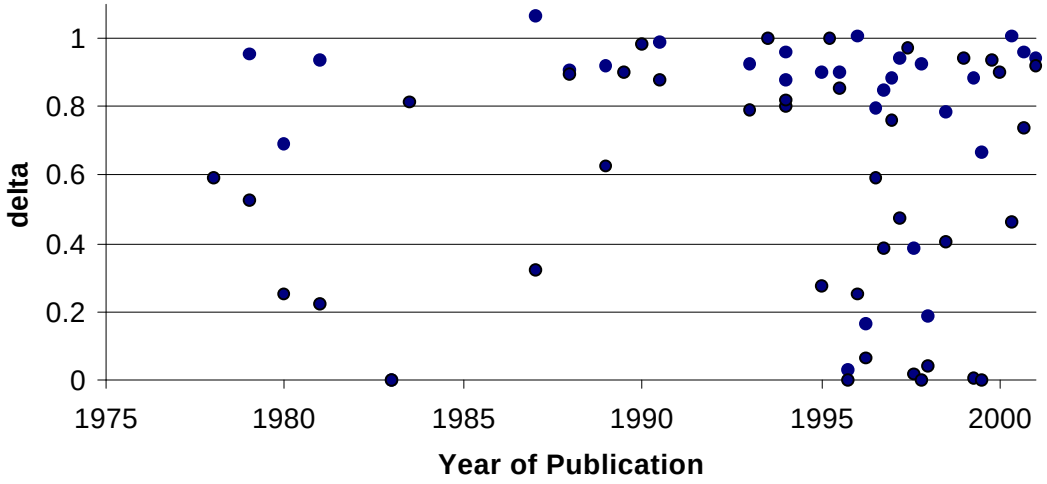
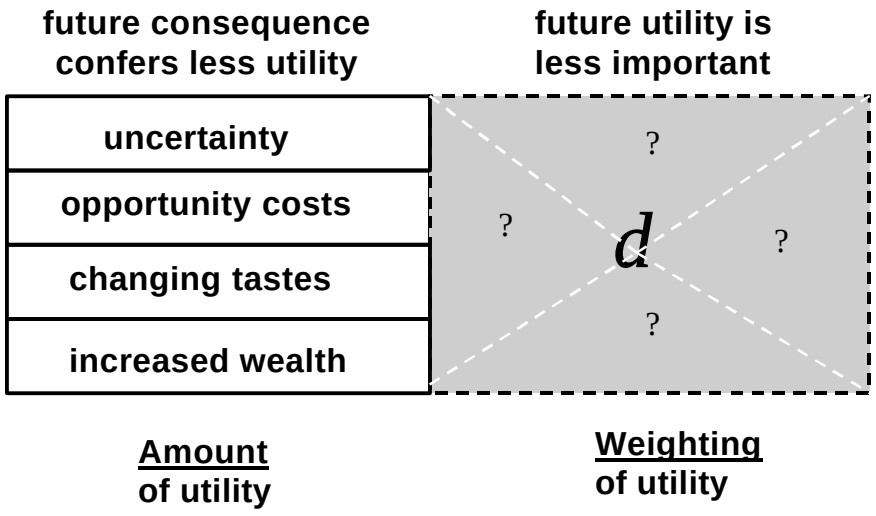


Figure 3


future consequence confers less utility
future utility is less important
uncertainty
opportunity costs
changing tastes
increased wealth
?
?
d
?
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Amount of utility
Weighting of utility