Intertemporal Choice

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17 December 2006

To appear in: Durlauf, S., & Blume, L. (Eds.) (2007). *The New Palgrave Dictionary of Economics* (2nd ed.). London: Palgrave Macmillan.

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Keywords: **intertemporal choice, theory of discounted utility, time preference, mortality, impatience, salience, positive economics, normative economics, revealed preference, felicity, instantaneous utility, discount rate, discount factor, exponential, dynamic consistency, dynamic inconsistency, generalized hyperbolas, quasi-hyperbolic, present-biased, quasi-geometric, preference reversal, sophisticated, naïve, partially naïve, neuroeconomics**, **addiction, impulsiveness**

1. Models of Intertemporal Choice

Most choices require decision-makers to trade off costs and benefits at different points in time. Decisions with consequences in multiple time periods are referred to as **intertemporal choices**. Decisions about savings, work effort, education, nutrition, exercise, and healthcare are all intertemporal choices.

The **theory of discounted utility** is the most widely used framework for analyzing intertemporal choices. This framework has been used to describe actual behavior (**positive economics**) and it has been used to *prescribe* socially optimal behavior (**normative economics**).

Descriptive discounting models capture the property that most economic agents prefer current rewards to delayed rewards of similar magnitude. Such **time preferences** have been ascribed to a combination of **mortality** effects, **impatience** effects, and **salience** effects. However, mortality effects alone can't explain time preferences, since mortality rates for young and middle-aged adults are at least 100 times too small to generate observed discounting patterns.

Normative intertemporal choice models divide into two approaches. The first approach accepts discounting as a valid normative construct, using **revealed preference** as a guiding principle. The second approach asserts that discounting is a normative mistake (except for a minor adjustment for mortality discounting). The second approach adopts zero discounting (or near-zero discounting) as the normative benchmark.

The most widely used discounting model assumes that total utility can be decomposed into a weighted sum—or weighted integral—of utility flows in each period of time (Ramsey, 1928):

$$U_t = \sum_{\tau=0}^{T-t} D(\tau) \cdot u_{t+\tau} .$$

In this representation: U_t is total utility from the perspective of the current period, t ; T is the last period of life (which could be infinity for an intergenerational model); $u_{t+\tau}$ is flow utility in period $t+\tau$ ($u_{t+\tau}$ is sometimes referred to as **felicity** or as **instantaneous utility)**; and $D(\tau)$ is the discount function. If delaying a reward reduces its value, then the discount function weakly *declines* as the delay, τ, *increases*:

$$D'(\tau) \leq 0 .$$

Economists normalize $D(0)$ to 1. Economists assume that increasing felicity, $u_{t+\tau}$, weakly increases total utility, U_t. Combining all of these assumptions implies,

$$1 = D(0) \geq D(\tau) \geq D(\tau') \geq 0,$$

where $0< \tau < \tau'$.

Time preferences are often summarized by the rate at which the discount function declines, $\rho(\tau)$. For differentiable discount functions, the **discount rate** is defined as

$$\rho(\tau) \equiv -\frac{D'(\tau)}{D(\tau)}.$$

The higher the discount rate the greater the preference for immediate rewards over delayed rewards. (See Laibson, 2003 for the formulae for non-differentiable discount functions.)

The **discount factor** is the inverse of the continuously compounded discount rate $\rho(\tau)$. So the discount factor is defined as

$$f(\tau) = \lim_{\Delta \to 0} \left(\frac{1}{1+\rho(\tau)\Delta} \right)^{1/\Delta} = e^{-\rho(\tau)}.$$

The lower the discount factor the greater the preference for immediate rewards over delayed rewards.

The most commonly used discount function is the **exponential** discount function:

$$D(\tau) = \delta^{\tau},$$

with $0 < \delta < 1$. For the exponential discount function, the discount rate is independent of the horizon, τ. Specifically, the discount rate is $-\ln(\delta)$ and the discount factor is δ. (***Figure 1*** shows three calibrated discount functions.)

The exponential discount function also has the property of **dynamic consistency**: preferences held at one point in time do not change with the passage of time (unless new information arrives). For example, consider the following investment opportunity: pay a utility cost of C at date $t = 2$ to reap a utility benefit of B at date $t = 3$. Suppose that this project is viewed from date $t = 1$ and judged to be worth pursuing. Hence, $-\delta C + \delta^2 B > 0$. Imagine that a period of time passes, and the agent reconsiders the project from the perspective of date $t = 2$. Now the project is still worth pursuing, since $-C + \delta B > 0$. To prove that this is true, note that the new expression is equal to the old expression multiplied by $1/\delta$. Hence, the $t = 1$ preference to complete the project is preserved at date $t = 2$. The exponential discount function is the *only* discount function that generates dynamically consistent preferences.

Despite its many appealing properties, the exponential discount function fails to match several empirical regularities. Most importantly, a large body of research has found that measured discount functions decline at a higher rate in the short run than in the long run. In other words, people appear to be more impatient when they make short-run tradeoffs—today vs. tomorrow—than when they make long-run tradeoffs—day 100 vs. day 101. This property has led psychologists (Herrnstein, 1961; Ainslie, 1992; Loewenstein & Prelec, 1992) to adopt discount functions in the family of **generalized hyperbolas**:

$$D(\tau) = \left(1+\alpha\tau\right)^{-\gamma/\alpha}.$$

Such discount functions have the property that the discount rate is higher in the short run than in the long run. Particular attention has been paid to the case in which $\gamma = \alpha$, implying that $D(\tau) = \left(1+\alpha\tau\right)^{-1}$.

Starting with Strotz (1956), economists have also studied alternatives to exponential discount functions. The majority of economic research has studied the **quasi-hyperbolic** discount function, which is usually defined in discrete time:

$$D(\tau) = \begin{Bmatrix} 1 & \text{if } \tau = 0 \\ \beta\cdot\delta^{\tau} & \text{if } \tau = 1,2,3,... \end{Bmatrix}.$$

This discount function was first used by Phelps and Pollak (1968) to study intergenerational discounting. Laibson (1997) subsequently applied this discount function to intra-personal decision problems. When $0 < \beta < 1$ and $0 < \delta < 1$ the quasi-hyperbolic discount function has a high short-run discount rate and a relatively low long-run discount rate. The quasi-hyperbolic discount function nests the exponential discount function as a special case ($\beta = 1$). Quasi-hyperbolic time preferences are also referred to as **present-biased** and **quasi-geometric**.

Like other non-exponential discount functions, the quasi-hyperbolic discount function implies that intertemporal preferences are not dynamically consistent. In other words, the passage of time may change an agent's preferences, implying that preferences are **dynamically inconsistent**. To illustrate this phenomenon, consider an investment project with a cost of 6 at date $t = 2$ and a delayed benefit of 8 at date $t = 3$. If $\beta = ½$ and $\delta = 1$ (see Akerlof, 1991), this investment is desirable from the perspective of date $t = 1$. The discounted value is positive:

$$\beta(-6+8) = ½(-6+8) = 1.$$

However, the project is undesirable from the perspective of date 2. Judging the project from the $t = 2$ perspective, the discounted value is negative:

$$-6 + \beta(8) = -6 + ½(8) = -2.$$

This is an example of a **preference reversal**. At date $t = 1$ the agent prefers to do the project at $t = 2$. At date $t = 2$ the agent prefers not to do the project. If economic agents foresee such preference reversals they are said to be **sophisticated** and if they do not foresee such preference reversals they are said to be **naïve** (Strotz, 1956). O'Donoghue and Rabin (2001) propose a generalized formulation in which agents are **partially naïve**: the agents have an imperfect ability to anticipate their preference reversals.

Many different microfoundations have been proposed to explain the preference patterns captured by the hyperbolic and quasi-hyperbolic discount functions. The most prominent examples include temptation models and dual-brain **neuroeconomic** models (Bernheim &

Rangel, 2004; Gul & Pesendorfer, 2001; McClure et al., 2004; Thaler & Shefrin, 1981). However, both the properties and mechanisms of time preferences remain in dispute.

2. Individual Differences in Measured Discount Rates

Numerous methods have been used to measure discount functions. The most common technique poses a series of questions, each of which asks the subject to choose between a sooner, smaller reward and a later, larger reward. Usually the sooner, smaller reward is an *immediate* reward. The sooner and later rewards are denominated in the same goods, typically amounts of money or other items of value. For example: "Would you rather have $69 today, or $85 in 91 days?" The subject's discount rate is inferred by fitting one or more of the discount functions described in the previous section to the subject choices. Most studies assume that the utility function is linear in consumption. Most studies also assume no intertemporal fungibility—the reward is assumed to be consumed the moment it is received. Many factors may confound the analysis in such studies, leading numerous researchers to express skepticism about the conclusions generated by laboratory studies. ***Table 1*** provides a summary of such critiques.

Discount functions may also be inferred from field behavior, such as consumption, savings, asset allocation, and voluntary adoption of forced-savings technologies (Angeletos et al., 2001; Shapiro, 2005; Ashraf et al., 2006). However, field studies are also vulnerable to methodological critiques. There is currently no methodological gold standard for measuring discount functions.

Existing attempts to measure discount functions have reached seemingly conflicting conclusions (Frederick, Lowenstein, & O'Donoghue, 2002). However, the fact that different methods and samples yield different estimates does not rule out consistent individual differences. Dozens of empirical studies have explored the relationship between individuals' estimated discount rates and a variety of behaviors and traits. A significant subset of this literature has focused on delay discounting and behavior in clinical populations, most notably drug users, gamblers, and those with other impulsivity-linked psychiatric disorders (see Reynolds, 2006 for a review). Other work has explored the relationship between discounting and traits such as age and cognitive ability. ***Table 2*** summarizes representative studies.

Smoking. A number of investigations have explored the relationship between cigarette smoking and discounting, together providing strong evidence that cigarette smoking is associated with higher discount rates (Baker, Johnson, & Bickel, 2003; Bickel, Odum, & Madden, 1999; Kirby & Petry, 2004; Mitchell, 1999; Ohmura, Takahashi, & Kitamura, 2005; Reynolds, Richards, Horn, & Karraker, 2004).

Excessive alcohol consumption. While the association with alcoholism has received relatively little attention, the available data suggests that problematic drinking is associated with higher discount rates. Heavy drinkers have higher discount rates than controls (Vuchinich & Simpson, 1998), active alcoholics discount rewards more than abstinent alcoholics, who in turn discount at higher rates than controls (Petry, 2001a), and detoxified alcohol-dependents have higher discount rates than controls (Bjork, Hommer, Grant, & Danube, 2004).

Illicit Drug Use. Recent studies document a positive association between discount rates and drug use for a variety of illicit drugs, most notably cocaine, crack-cocaine, heroin, and amphetamines (Petry, 2003; Coffey, Gudleski, Saladin, & Brady, 2003; Bretteville-Jensen, 2004; Kirby & Petry, 2004).

Gambling. Pathological gamblers have higher discount rates than controls, both in the laboratory (Petry, 2001b) and in the field (Dixon, Marley, & Jacobs, 2003), and among a population of gambling and non-gambling substance abusers (Petry & Casarella, 1999). Moreover, Alessi and Petry (2003) report a significant, positive relationship between a gambling severity measure and the discount rate within a sample of problem gamblers. Petry (2001b) finds that gambling frequency during the previous three months correlates positively with the discount rate.

Age. Patience appears to increase across the lifespan, with the young showing markedly less patience than middle-aged and older adults (Green, Fry, & Myerson, 1994; Green, Myerson, Lichtman, Rosen, & Fry, 1996; Green, Myerson, Ostazewski, 1999). Read & Read (2004) report that older adults (mean age = 75) are the most patient age group when delay horizons are only a year. However, this study also finds that older adults are the *least* patient group when delay horizons are 3–10 years. This reversal probably reflects the fact that 75-year-olds face significant mortality/disability risk at horizons of 3–10 years.

Cognitive Ability. Kirby, Winston, and Santiesteban (2005) report that discount rates are correlated negatively with grade point average in two college samples. Benjamin, Brown, and Shapiro (2006) find an inverse relationship between individual discount rates and standardized (mathematics) test scores for Chilean high school students and Harvard undergraduates. Silva and Gross (2004) show that students scoring in the top third of their introductory psychology course have lower discount rates than those scoring in the middle and lower thirds. Frederick (2005) shows that participants scoring high on a “cognitive reflection” problem-solving task demonstrate more patient intertemporal choices (for a variety of rewards) than those scoring low. Finally, in a sample of smokers, Jaroni et al. (2004) report that participants who did not attend college had higher discount rates than those attending at least some college.

All of these empirical regularities are consistent with the neuroeconomic hypothesis that prefrontal cortex is essential for patient (forward-looking) decision-making (McClure et al., 2004). This area of the brain is slow to mature, is critical for general cognitive ability (Chabris, 2007), and is often found to be dysfunctional in addictive and other psychiatric disorders.

More research is required to clarify the cognitive and neurobiological bases of intertemporal preferences. Future research should evaluate the usefulness of measured discount functions in predicting real-world economic decisions (Ashraf et al., 2006). Finally, ongoing research should improve the available methods for measuring intertemporal preferences.

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Figure 1. Three calibrated discount functions (see text for explanation).

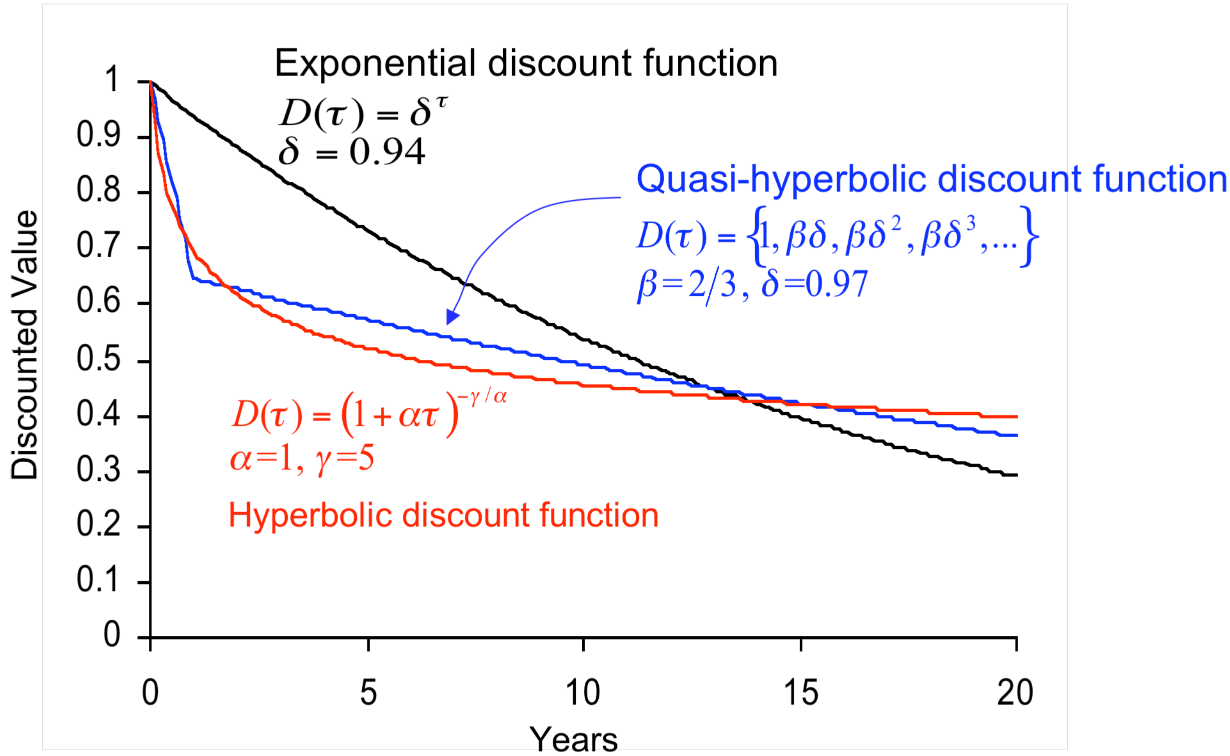

Table 1. Potential confounds that may arise when attempting to measure discount rates in laboratory studies.

Factor	Description
Unreliability of future rewards	A subject may prefer an earlier reward because the subject thinks she is unlikely to actually receive the later reward. For example, the subject may perceive an experimenter as unreliable.
Transaction costs	A subject may prefer an immediate reward because it is paid in cash, whereas the delayed reward is paid in a form that generates additional transaction costs. For example, a delayed reward may need to be collected, or it may arrive in the form of a check that needs to be cashed.
Hypothetical rewards	A subject may not reveal her true preferences if she is asked hypothetical questions instead of being asked to make choices with real consequences. However, researchers who have directly compared real and hypothetical rewards have concluded that this difference does not arise in practice (Johnson & Bickel, 2002; Madden et al., 2003).
Investment versus consumption	Some subjects may interpret a choice in a discounting experiment as an *investment* decision and not a decision about the timing of consumption. For example, a subject might reason that a later, larger reward is superior to a sooner, smaller reward as long as the return for waiting is higher than the return available in financial markets.
Consumption versus receipt	Rewards, especially large ones, may not be consumed at the time they are received. For example, a $500 reward is likely to produce a stream of higher consumption, not a lump of consumption at the date of receipt. Such effects may explain why large-stake experiments are associated with less measured discounting than small-stake experiments.
Curvature of utility function	A subject may prefer a sooner, smaller reward to a later, larger reward if the subject expects to receive other sources of income at that later date. In general, a reward may be worth less if it is received during a period of relative prosperity.
Framing effects	The menu of choices or the set of questions may influence the subject's choices. For example, if choices between $1.00 now and delayed amounts ranging between $1.01 and $1.50 were offered, subjects may switch preference from early to later rewards at an interior threshold—e.g. $1.30. However, if choices between $1.00 and delayed amounts ranging between $1.51 and $2.00 were offered, the switch might happen at a much higher threshold—e.g. $1.70—implying a much higher discount rate.
Demand characteristics	Procedures for estimating discount rates may bias subject responses by implicitly guiding their choices. For example, the phrasing of an experimental question can imply that a particular choice is the right or desired answer (from the perspective of the experimenter).

Table 2. Representative empirical studies linking estimated discount rates for monetary rewards to various individual behaviors and traits. Studies marked with an asterisk (*) used hypothetical rewards; others used real rewards. *N* = total # of participants in study.

Variable	Study	*N*	Discount Rate Findings
Nicotine	Bickel, Odum, & Madden (1999)*	66	Current smokers > never-smokers and ex-smokers
Alcohol	Bjork, Hommer, Grant, & Danube (2004)	160	Abstinent alcohol-dependent subjects > controls
Cocaine	Coffey, Gudleski, Saladin, & Brady (2003)*	25	Crack-dependent subjects > matched controls[a]
Heroin	Kirby, Petry, & Bickel (1999)	116	Heroin addicts > age-matched controls
Gambling	Petry (2001b)*	86	Pathological gamblers[b] > controls
Risky Behavior	Odum, Madden, Badger, & Bickel (2000)*	32	Heroin addicts agreeing to share needle in a hypothetical scenario > non-agreeing addicts
Age	Green, Fry, & Myerson (1994)*	36	Children > young adults > older adults
Psychiatric Disorders	Crean, de Wit, & Richards (2000)	24	"High risk" patients[c] > "low risk" patients
Cognitive Ability	Benjamin, Brown, & Shapiro (2006)	92	Low scorers on standardized mathematics test > high scorers

Notes: (*a*) Results based on those choices falling within the delay range of 1 week to 25 years. Overall analyses including shorter delays (5 minutes to 5 days) also revealed the same effect, but with smaller magnitude. (*b*) Gamblers with comorbid substance abuse disorders showed a greater effect than gamblers without such disorders. (*c*) "High risk" patients were those diagnosed with disorders carrying high risk for impulsive behavior, according to *DSM-IV* criteria, such as patients with borderline personality disorder, bipolar disorder, and substance abuse disorders.