

The Cost of Keeping Track

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Abstract

I show that a lump-sum cost incurred for keeping track of future transactions predicts several known departures from the standard discounting model: an agent who incurs such costs will exhibit decreasing impatience with preference reversals; a magnitude effect, i.e. discounting large amounts less than small amounts; a sign effect, i.e. discounting gains more than losses; and an Andreoni-Sprenger (2012) type reduction of discounting and decreasing impatience when delayed outcomes are added onto existing delayed outcomes. In addition, agents of this type will under certain circumstances prefer to “pre-crastinate”, i.e. incur losses sooner rather than later, which is a common feature of everyday experience but is currently not captured in discounting models. Additionally, the model generates loss aversion, one of the hallmarks of prospect theory. Finally, the model predicts status quo bias and default choice. In particular, it predicts that agents will fail to adopt profitable technologies, not because they do not value them, but because they forget to undertake the steps necessary to use them. The model further predicts that this problem can be alleviated through reminders, for which agents are willing to pay. Examples in development economics include SMS reminders to save, chlorine dispensers at the water source, vaccination camps, and reminders to use fertilizer.

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1 Introduction

Individuals often have to keep track of future transactions. For instance, when a person makes a decision to pay a bill not now, but later, she has to keep this in mind and perform an action later to implement the decision (e.g. logging into her online bank account and making the transfer). If she fails to make the transfer, she may face a late fee. Similarly, when she expects a payment, she is likely to keep track of the incoming payment by verifying whether it arrived in her bank account. If she fails to keep track of the incoming payment, it may get lost and she may have to pay a hassle cost to follow up on it.

The basic premise of this paper is that such “keeping track” generates costs for the agent. This cost can come in several forms: agents may forget about the future transaction, resulting in a penalty such as a late fee, or a hassle cost to salvage the transaction. Additionally, simply having to keep the task in mind may generate a psychological cost; this cost may be avoidable through reminders, but these in turn may be costly to set up. In either case, the agent integrates into her decision today the cost of keeping track of future transactions.

This simple addition to the standard model turns out to predict several anomalies of time discounting that the literature has documented: decreasing impatience and preference reversals; the magnitude effect; the sign effect; and a reduction of discounting and hyperbolicity when delayed outcomes are added to existing delayed outcomes. In addition, the model explains why individuals under some circumstances prefer to “pre-crastinate”, i.e. “get painful transactions over with”. This phenomenon has recently been empirically demonstrated (Rosenbaum et al., 2014), but is not captured by existing discounting models. Moreover, the model predicts loss aversion for future outcomes: both future gains and losses are less attractive due to the cost of keeping track, which decreases the utility of future gains but increases the disutility of future losses, leading to loss aversion.

The particular form of the cost of keeping track matters for some of these results, but not for others. In particular, when the cost of keeping track is lump-sum, agents will exhibit decreasing impatience and preference reversals in discounting, the magnitude effect, and the Andreoni-Sprenger (2012) type reduction of discounting and decreasing impatience when delayed outcomes are added onto existing delayed outcomes. A lump-sum cost of keeping track is realistic in cases where penalties for forgetting about everyday transactions come in lump-sum form. For instance, communications companies and banks frequently impose lump-sum penalties for late bill payment. In contrast, the sign effect, “pre-crastination”, loss aversion for future outcomes, and status quo bias and default choice can be produced without the lump-sum assumption. Section 2.3 discusses different functional forms for the cost of keeping track.

Finally, the model predicts status quo bias and default choice, and in particular that agents will fail to adopt profitable technologies. Lack of demand for profitable technologies is a common phenomenon especially in developing countries. The model suggests one possible reason for this inefficiency: when people face an opportunity to adopt technology, they often cannot act on it

immediately, but instead have to make a plan to do it later. For instance, when people fetch water at a source, they might be reminded that they want to chlorinate their water. However, when opportunities to chlorinate are not available at the source, they have to make a plan to do it later, e.g. when they reach their home where they store their chlorine bottle. However, at the later timepoint when they can act on their plan, they have forgotten about it – in this example, by the time they reach the homestead, they do not remember to use the chlorine bottle. The model captures this phenomenon, and predicts that when reminders are provided at the right time – e.g., at the water source – adoption should be high. Indeed, Kremer et al. (2009) show that dispensers at the water source can dramatically increase takeup. Other authors have documented similar failures to adopt technology, and shown that reminders at the right time – i.e., when people can act on them – can increase takeup: timed discounts after the harvest can increase fertilizer usage among farmers (Duflo et al., 2009), vaccination camps and small gifts can increase vaccination rates for children (Banerjee et al., 2010), and text message reminders can increase savings rates (Karlan et al., 2010). The model makes quantitative predictions about the willingness of sophisticates to pay for such reminders.

The remainder of the paper is organized as follows. Section 2 presents a simple version of the model in which utility is linear and the cost of keeping track is constant and lump-sum. Section 3 discusses a number of alternative formulations for the shape of the cost of keeping track. Section 4 shows that most results hold for any concave and monotonically increasing utility function. Section 5 describes a few applications of the model in the developing world. Section 6 concludes.

2 The Model

2.1 A two-period model

We begin with a simple two-period model in which “tasks” and “opportunities” arise at the beginning of period 0. A task is a payment to be made; an opportunity is a payment to be received. When a task or opportunity arises, the agent either decides to act on it in period 0, or to act on it in period 1. Acting on a task or opportunity consists in performing a costless action a . For instance, in the case of paying a bill, acting on the task consists in making the required bank transfer or writing a check; in the case of receiving a payment, acting on the opportunity might consist in first sending one’s bank details to the sender and verifying that the payment has arrived. Each task or opportunity is defined by the payoff of acting on it immediately, x_0 , and the payoff of acting on it later, x_1 , with $x_1 \geq x_0$. These payoffs accrue in the period in which the agent acts on the task or opportunity.¹

¹This assumption is important for the results that follow, but it is not obvious and bears justification. Specifically, under the permanent income hypothesis, agents integrate the anticipated gain or loss into their consumption path as soon as it is announced, and they adjust consumption immediately following the announcement. In contrast, the present setup assumes that agents actually experience a (possibly transient) increase or decrease in consumption (or

The core assumption of the model is that when an agent decides to act on a task or opportunity in period 1, she incurs a cost c . I begin by modeling this cost as a lump-sum cost; Section 3 extends the framework to other formulations. Similarly, I begin by using linear utility; this choice is motivated by the fact that for the relatively small magnitude of the transactions which this model concerns, linear utility is a reasonable approximation. Section 4 provides a more general treatment.

Gains I now ask how agents behave when they are presented with an opportunity on which they can act now or later. For instance, they may receive a check in the mail which they can cash immediately or later; they may decide between selling stock now or later; or in an analogous experiment, they may face a choice between a smaller amount available sooner or a larger amount available later.

The utility of acting in period 0 is:

$$u_0^+ = x_0 \tag{1}$$

The utility of acting in period 1 is:

$$u_1^+ = \beta(x_1 - c) \tag{2}$$

Thus, for acting in period 1, agents anticipate the discounted period 1 payoff, x_1 , less the discounted cost of keeping track of the opportunity. The condition for preferring to act in period 1 is $u^1 > u^0$, which simplifies to:

$$x_1 > \frac{x_0}{\beta} + c \tag{3}$$

Thus, agents prefer to act in period 1 if the future gain exceeds the future-inflated value of the small-soon gain and the cost of keeping track.

Losses I now extend this framework to losses, by asking how agents behave when they are presented with a task which they can complete now or later. For instance, they may receive a bill in the mail which they can pay immediately or later; farmers may decide between buying fertilizer now or later; or participants in an experiment may face a choice between losing a smaller amount of money immediately, or losing a larger amount later. To preserve the analogy to the framework for gains, I consider the utility of a smaller loss $-x_0$ incurred in period 0, and that of a larger loss $-x_1$ incurred in period 1. If they choose the larger loss in period 1, agents additionally pay the cost of keeping track. The utilities are thus as follows:

utility) in the period when they actually incur the gain or loss. Which of these competing claims is true? Empirical evidence sides with the latter; a large number of studies show that consumption smoothing in real life is imperfect, i.e. people consume somewhat less in periods in which they incur losses (“lean season”), and somewhat more in periods in which they incur gains (payday effects).

$$u_0^- = -x_0 \tag{4}$$

$$u_1^- = \beta(-x_1 - c) \tag{5}$$

The condition for acting in period 1 is again given by $u_1 > u_0$, which simplifies to:

$$x_1 < \frac{x_0}{\beta} - c \tag{6}$$

Thus, agents prefer to delay losses if the future loss $-x_1$ is sufficiently small relative to the immediate loss net of the cost of keeping track.

I now discuss the implications of this framework for choice behavior.

Proposition 1. *Steeper discounting of gains: With a positive cost of keeping track, agents discount future gains more steeply than otherwise.*

Proof. From 2, it is easy to see that $\frac{\partial u_1^+}{\partial c} = -\beta$. Thus, the discounted value of future gains decreases in the cost of keeping track, c ; agents discount future gains more steeply the larger the cost of keeping track. \square

One implication of this result is that agents discount future outcomes at a higher rate than given by their time preference parameter. For instance, even agents who discount at the interest rate will exhibit choice behavior that looks like much stronger discounting when the cost of keeping track is high. The high discount rates frequently observed in experiments may partly be accounted for by participants correctly anticipating the cost of keeping track of the payment. For instance, in a standard discounting experiment, participants may be given a voucher to be cashed in in the future; with a positive probability of losing these vouchers, or of automatic payments not arriving, the future will be discounted more steeply than otherwise.

Proposition 2. *Shallower discounting of losses: With a positive cost of keeping track, agents discount future losses less steeply than otherwise.*

Proof. As above, it follows from 5 that $\frac{\partial u_1^-}{\partial c} = -\beta$. Thus, the discounted utility of future losses decreases in the cost of keeping track, c ; put differently, the disutility of future losses increases in c , i.e. future losses are discounted less as the cost of keeping track rises. \square

Intuitively, both delayed losses and delayed gains become less attractive because of the penalty for forgetting, which corresponds to steeper discounting for gains and shallower discounting for losses.

Proposition 3. *Pre-crastination: When agents choose between an equal-sized immediate vs. delayed loss, they prefer to act in period 1 when the cost of keeping track is zero, but may prefer to “pre-crastinate” if with a positive cost of keeping track.*

Proof. When the payoffs of acting now vs. acting later are both $-\bar{x}$, and $c = 0$, the condition for acting later on losses given in Equation 6 simplifies to $\bar{x} < \frac{\bar{x}}{\beta}$, which is always true with $\beta < 1$. Thus, when agents choose between equal-sized immediate vs. delayed losses and $c = 0$, they prefer to act in period 1. However, when $c > 0$, agents may prefer to act in period 0: the condition for acting in period 0 implied by 4 and 5 is $-\bar{x} > \beta(-\bar{x} - c)$, which simplifies to

$$c > \frac{1 - \beta}{\beta} \bar{x}$$

When this condition is met, i.e. the cost of keeping track of having to act later is large enough, agents prefer to incur the loss in period 0 rather than period 1, i.e. they “pre-crastinate”. \square

Under standard discounting, agents want to delay losses: a loss is less costly when it is incurred in the future compared to today. However, if the risk and penalty for forgetting to act in period 1 are sufficiently large relative to the payoff, agents prefer to act in period 0, i.e. they “pre-crastinate”. For instance, such individuals may prefer to pay bills immediately because making a plan to pay them later is costly. This phenomenon corresponds well to everyday experience, and has recently been empirically demonstrated (Rosenbaum et al., 2014). However, it is not captured by standard discounting models, under which agents weakly prefer to delay losses.

Proposition 4. *Sign effect: With a positive cost of keeping track, agents discount gains more than losses.*

Proof. I show that the absolute value of the utility of a delayed loss is greater than that of a delayed gain, which corresponds to greater discounting of gains than losses. The absolute value of the utility of a delayed loss is

$$|u_1^-| = |\beta(-x_1 - c)| = \beta(x_1 + c)$$

Because $u_1^+ = \beta(x_1 - c)$, it is easy to see that $|u_1^-| > u_1^+$. \square

This result produces a the sign effect, a well-known departure of empirically observed time preferences from standard discounting models: agents discount losses less than gains.

Proposition 5. *Loss aversion: With a positive cost of keeping track, agents exhibit loss aversion for future outcomes.*

Proof. Follows directly from Proposition 4. \square

Proposition 6. *Magnitude effect: With a positive cost of keeping track, agents discount large amounts less than small amounts.*

Proof. Consider the utilities of acting now vs. later when both payoffs are multiplied by a constant $A > 1$:

$$u_0 = Ax_0$$

$$u_1 = \beta(Ax_1 - c)$$

The condition for acting in period 1 is now:

$$x_1 > \frac{x_0}{\beta} + \frac{c}{A}$$

Recall that the condition for acting on gains in period 1 with $c > 0$ is $x_1 > \frac{x_0}{\beta} + c$. Because $\frac{c}{A} < c$, the condition for acting in period 1 is easier to meet when the two outcomes are larger; thus, large outcomes are discounted less than small ones. Note that this model predicts no magnitude effect when both outcomes are in the future. \square

Proposition 7. *Decreasing impatience and preference reversals: With a positive cost of keeping track, agents exhibit decreasing impatience and time-inconsistent preference reversals.*

Proof. When both outcomes are moved one period into the future, they are both subject to the risk and penalty of forgetting; their utilities are:

$$u_1 = \beta(x_0 - c)$$

$$u_2 = \beta^2(x_1 - c)$$

The condition for acting later is

$$x_1 > \frac{x_0}{\beta}$$

Note that this condition is easier to meet than condition 3 for choosing between acting immediately vs. next period, which is $x_1 > \frac{x_0}{\beta} + c$. Thus, when both outcomes are delayed into the future, the cost of waiting is smaller. As the future approaches, this will produce the preference reversals, a well-known empirical fact about discounting. \square

Proposition 8. *Andreoni-Sprenger convex budgets, Effect 1: With a positive cost of keeping track, agents exhibit less discounting when adding money to existing payoffs than otherwise.*

Proof. Assume a fixed initial payoff \bar{x} in both periods 0 and 1. The lifetime utility of the agent in the absence of other transfers is

$$U(\bar{x}, \bar{x}) = \bar{x} + \beta(\bar{x} - c)$$

Now consider how this utility changes after adding x_0 in period 0 or x_1 in period 1:

$$U(\bar{x} + x_0, \bar{x}) = \bar{x} + x_0 + \beta(\bar{x} - c)$$

$$U(\bar{x}, \bar{x} + x_1) = \bar{x} + \beta(\bar{x} + x_1 - c)$$

The condition for acting later is $U(\bar{x}, \bar{x} + x_1) > U(\bar{x} + x_0, \bar{x})$, which simplifies to

$$x_1 > \frac{x_0}{\beta}$$

Note that this condition is again easier to meet than than condition 3 for choosing between acting immediately vs. next period *without* pre-existing payoffs at these timepoints. Thus, agents exhibit less discounting when money is added to existing payoffs than otherwise. \square

In their study on estimating time preferences from convex budgets, Andreoni & Sprenger (2012) pay the show-up fee of \$10 in two instalments: \$5 on the day of the experiment, and \$5 later. Even the payment on the day of the experiment is delivered to the student's mailbox rather than given at the time of the experiment itself, thus holding the cost of keeping track constant. The additional cost of payments now vs. later is thus minimal. Andreoni & Sprenger (2012) find much lower discount rates than most other studies on discounting. This finding is reflected in the result above.

Proposition 9. *Andreoni-Sprenger convex budgets, Effect 2: With a positive cost of keeping track, agents exhibit no hyperbolic discounting when adding money to existing payoffs.*

Proof. Assume again a fixed initial payoff \bar{x} in both periods, but now move these periods one period into the future. The lifetime utility of the agent is

$$U = \beta(\bar{x} - c) + \beta^2(\bar{x} - c)$$

Now consider how this utility changes after adding x_0 in period 1, or x_1 in period 2:

$$U(0, \bar{x} + x_0, \bar{x}) = \beta(\bar{x} + x_0 - c) + \beta^2(\bar{x} - c)$$

$$U(0, \bar{x}, \bar{x} + x_1) = \beta(\bar{x} - c) + \beta^2(\bar{x} + x_1 - c)$$

The condition for acting later, $U(0, \bar{x}, \bar{x} + x_1) > U(0, \bar{x} + x_0, \bar{x})$, simplifies to

$$x_1 > \frac{x_0}{\beta}$$

Note that this condition is the same as that obtained in Proposition 8. Thus, when money is added to existing payoffs now vs. next period, and when money is added to existing payoffs in two consecutive periods in the future, the conditions for preferring to act later are the same. This model therefore produces no decreasing impatience or preference reversals when adding money to existing payoffs. This mirrors the second result in Andreoni & Sprenger’s (2012) study. \square

Together, these results predict many of the anomalies that characterize empirically obtained discount functions. Figure 1 summarizes the magnitude and sign effects and hyperbolic discounting graphically.

3 Anatomy of the cost of keeping track

In the previous section, the cost of keeping track was a lump-sum to simplify exposition. In this section I consider a few variations. The key result is that most of the results above hold for different formulations of the cost of keeping track.

3.1 The risk of forgetting

Perhaps the most compelling argument in support of the assumption that agents incur a cost for keeping track of future transactions is the fallibility of human memory. If agents are more likely to forget acting on future transactions than current transactions, this naturally leads to the results derived in the previous sections. Specifically, assume that when an agent makes a plan to act on a task or opportunity in the future, she actually performs the required action with probability $1 - p < 1$, and forgets to perform the action with probability $p > 0$. If she forgets to perform the action required to act on the task or opportunity, the agent receives a smaller payoff $x_D < x_1$; in the case of losses, she incurs a greater loss, $-x_D < -x_1$. We can think of the difference between x_D and x_1 as the penalty c for forgetting to act, with $c = x_1 - x_D > 0$ for gains and $c = x_D - x_1 > 0$ for losses. For instance, the agent can still cash a check that she forgot to cash by the deadline, but incurs a cost to “salvage” the transaction, e.g. by paying an administrative fee to have a new check issued. Similarly, if the agent fails to pay a bill by the deadline, the bill will still be paid, but the agent now has to pay a late fee. Thus, the utility for gains is now as follows:

$$u_1^+ = \beta [(1 - p)x_1 + px_D]$$

With the penalty for forgetting given by $c = x_1 - x_D > 0$, this simplifies to:

$$u_1^+ = \beta (x_1 - pc)$$

Similarly, the utility for losses is:

$$u_1^- = \beta [(1 - p)(-x_1) + p(-x_D)]$$

With the penalty for forgetting given by $c = x_D - x_1 > 0$, this simplifies to:

$$u_1^- = \beta [-x_1 - pc]$$

Note that both of these utilities are variants of the utilities obtained with a lump-sum cost of keeping track in 2 and 5; here, the cost c is additionally multiplied with the probability that it will be incurred. Because both p and c are constant for all future periods, this formulation yields the same results as those in section 2.1.

3.1.1 The shape of the forgetting function

From the previous discussion, naturally the question arises whether a constant probability of forgetting for all future periods is justified. Indeed, this particular choice is motivated by the current consensus in psychology about the empirical shape of the forgetting function: as was first casually observed by the German psychologist Jost in 1897, and confirmed by Wixted and colleagues (e.g. Wixted, 2004) and many other studies since, the shape of the psychological forgetting function is not well described by an exponential function, but follows instead a power law, such as a hyperbola. Note that a fixed probability of forgetting attached to future but not present transactions is a quasi-hyperbolic forgetting function similar to that used for discounting by Strotz (1956) and Laibson (1997). This assumption generates decreasing impatience and preference reversals.

3.1.2 Beyond forgetting: reminders and hassle costs

Having imperfect memory might not be a problem if agents anticipate their own probability of forgetting to act in the future (as we have assumed so far), and can set up costless reminders to overcome this risk. However, I argue that truly effective reminders are unlikely to be costless. First, even the small act of making a note in one's diary about the future task or opportunity are *hassle costs* that can be cumbersome. Second, such simple reminders are not bullet-proof, and truly effective reminders are likely to be much more costly. For instance, consider the actions you would have to undertake to avoid forgetting an important birthday with a probability of one. Writing it in a diary is not sufficient because you might forget to look at it. Setting an alarm, e.g. on a phone, might fail because the phone might be out of battery at the wrong time. A personal assistant might forget himself to issue the reminder to you. Likely the most effective way of ensuring that the birthday is not forgotten would be to hire a personal assistant whose *sole* assignment is to issue the reminder. Needless to say, this would be rather costly. Cheaper versions of the same arrangement would come at the cost of lower probabilities of the reminder being effective.

Finally, even if agents have perfect memory, they may incur a psychological cost for keeping transactions in mind. The psychological cost of juggling many different tasks has recently attracted increased interest in psychology and economics. Most prominently, Shafir & Mullainathan (2013) argue that the poor in particular may have so many things on their mind that only the most pressing receive their full attention. This argument implies that a) allocating attention to a task is not costless, and b) the marginal cost of attention is increasing in the number of tasks. Together, this reasoning provides an intuition for a positive *psychological* cost of keeping track of future transactions, even with perfect memory and no financial costs of keeping track.

3.2 A proportional cost of keeping track

In the previous exposition, the cost of keeping track was a lump-sum cost that was subtracted from future payoffs. In this section, I ask how the results obtained with a lump-sum cost would change if the cost were instead a fraction α of the original payoff. The utility of gains is then given by:

$$u_1^+ = \beta(1 - \alpha)x_1 \tag{7}$$

Analogously, the utility for losses is given by:

$$u_1^- = \beta(1 + \alpha)(-x_1) \tag{8}$$

The condition for choosing the larger, later gain is

$$x_1 > \frac{x_0}{\beta(1 - \alpha)} \tag{9}$$

Analogously, the condition for choosing the larger, later loss is

$$x_1 < \frac{x_0}{\beta(1 + \alpha)} \tag{10}$$

Note that in the gains domain, this formulation for the cost of keeping track creates the quasi-hyperbolic discounting model (Strotz, 1956; Laibson, 1996), which measures exponential period-by-period discounting through the parameter δ , which corresponds to β in the present model, and hyperbolicity through the β parameter which is multiplied onto any future outcome; this parameter corresponds to $(1 - \alpha)$ in the present model. Thus, in the gains domain, the present model with a cost of keeping track model that is a fraction of the original payoff generates the same results as the quasi-hyperbolic discounting model.

Specifically, with a positive cost of keeping track, agents discount more than they would otherwise; it is easy to see from equation 7 that $\frac{\partial u_1^+}{\partial \alpha} < 0$. Thus, Proposition 1 continues to hold with a proportional cost of keeping track. Moreover, because the same proportional cost applies to all future transactions, but not present transactions, the model with a proportional cost of keeping track generates decreasing impatience. Consider the utilities if the choice between x_0 immediately and x_1 next period is moved one period into the future. The period 1 utility is then given by

$$u_1^+ = \beta(1 - \alpha)x_0$$

and the period 2 utility is given by

$$u_2^+ = \beta^2(1 - \alpha)x_1$$

The condition for choosing the larger, later outcome is

$$x_1 > \frac{x_0}{\beta}$$

Note that this condition is easier to meet than condition 9; thus, agents exhibit decreasing impatience, and Proposition 7 therefore continues to hold. Thus, in the gains domain, the model with a proportional cost coincides with the quasi-hyperbolic discounting model and makes the same core predictions.

However, the two models differ in the loss domain: while the quasi-hyperbolic model discounts both gains and losses with the same parameters, in the present model, the cost-of-keeping-track parameter is $1 + \alpha$ for losses (since a larger loss is incurred when agents fail to keep track of the transaction), while it is $1 - \alpha$ for gains (since a smaller gain is obtained when agents fail to keep track). As a result, the present model predicts the sign effect in discounting, loss aversion for future transactions, and pre-crastination.

To see the sign effect, compare the absolute value of a delayed loss to that of a delayed gain:

$$|u_1^-| = |\beta(1 + \alpha)(-x_1)| = \beta(1 + \alpha)x_1 > \beta(1 - \alpha)x_1 = u_1^+$$

Thus, the absolute value of the utility of a delayed loss is greater than that of a delayed gain, which implies greater discounting of gains than losses. This result corresponds to that of Proposition 4 above. By the same reasoning, loss aversion for delayed outcomes (Proposition 5) continues to hold with a proportional cost of keeping track.

To see that agents may prefer to pre-crastinate with a proportional cost of keeping track, consider the case where the payoffs of acting now vs. acting later are both $-\bar{x}$. When $\alpha = 0$, the condition for acting later on losses given in Equation 10 simplifies to $\bar{x} < \frac{\bar{x}}{\beta}$, which is always true with $\beta < 1$.

Thus, when agents choose between equal-sized immediate vs. delayed losses and $\alpha = 0$, they prefer to act in period 1. However, when $\alpha > 0$, agents may prefer to act in period 0: the condition for acting in period 0 implied by 4 and 8 is

$$-\bar{x} > \beta(1 + \alpha)(-\bar{x})$$

which simplifies to

$$\alpha > \frac{1 - \beta}{\beta}$$

Thus, when the proportional cost of keeping track is sufficiently high relative to the cost of waiting, agents prefer to pre-castinate.

Finally, with a cost of keeping track that is a fraction of the original payoff, agents will not exhibit a magnitude effect or the Andreoni-Sprenger (2012) type reduction of discounting and hyperbolicity when money is added to existing payoffs. This is because a proportional cost of keeping track scales linearly with the payoff, and therefore the condition for choosing a larger delayed payoff over a smaller, sooner payoff does not change when both payoffs are multiplied with a constant:

$$\beta(1 - \alpha)Ax_1 > Ax_0$$

In this expression, A cancels, yielding the same condition as for smaller payoffs. Thus, the magnitude effect does not obtain with a proportional cost of keeping track and linear utility.

For the same reason, the Andreoni-Sprenger (2012) type reduction of discounting and decreasing impatience when money is added to existing payoffs no longer holds with a proportional cost of keeping track. As before, assume a fixed initial payoff \bar{x} in both periods 0 and 1. The lifetime utility of the agent after adding x_0 in period 0 or x_1 in period 1 is given by:

$$U(\bar{x} + x_0, \bar{x}) = \bar{x} + x_0 + \beta(1 - \alpha)\bar{x}$$

$$U(\bar{x}, \bar{x} + x_1) = \bar{x} + \beta(1 - \alpha)(\bar{x} + x_1)$$

The condition for acting later is $U(\bar{x}, \bar{x} + x_1) > U(\bar{x} + x_0, \bar{x})$, which simplifies to

$$x_1 > \frac{x_0}{\beta(1 - \alpha)}$$

Note that this condition is the same as the basic condition 9; thus, with a proportional cost of keeping track, agents do not exhibit the Andreoni-Sprenger (2012) type reduction in discounting shown for a lump-sum cost of keeping track in Proposition 8.

Similarly, the reduction of hyperbolicity when money is added to existing payoffs no longer holds for a proportional cost of keeping track. Assume again a fixed initial payoff \bar{x} in both periods, but now move these periods one period into the future. Then consider how this utility changes after adding x_0 in period 1, or x_1 in period 2. The lifetime utility of the agent is

$$U(0, \bar{x} + x_0, \bar{x}) = \beta(1 - \alpha)(\bar{x} + x_0) + \beta^2(1 - \alpha)\bar{x}$$

$$U(0, \bar{x}, \bar{x} + x_1) = \beta(1 - \alpha)\bar{x} + \beta^2(1 - \alpha)(\bar{x} + x_1)$$

The condition for acting later, $U(0, \bar{x}, \bar{x} + x_1) > U(0, \bar{x} + x_0, \bar{x})$, simplifies to

$$x_1 > \frac{x_0}{\beta}$$

Note that this condition is the same as that obtained in Proposition 9. There, it was identical to the condition obtained for immediate vs. delayed payoffs from Proposition 8, and therefore the formulation with a lump-sum cost of keeping track predicted no decreasing impatience when money is added to existing payoffs at both timepoints. However, with a proportional cost of keeping track, the condition when both periods are in the future, $x_1 > \frac{x_0}{\beta}$, is less stringent than that when one outcome is immediate, $x_1 > \frac{x_0}{\beta(1-\alpha)}$; therefore a proportional cost of keeping track does not predict the lack of hyperbolicity when money is added to existing payoffs observed by Andreoni & Sprenger (2012).

3.3 Combining the risk of forgetting with a proportional cost of keeping track

The previous two sections discussed the implications of modeling the cost of keeping track as the probability of forgetting to act on future tasks and opportunities, and of modeling it as a proportion of the original payoff. It is interesting to ask whether and how the results change when we combine these cases, i.e. model the cost of keeping track as the probability of forgetting with a proportional penalty for forgetting. In this case, the utility for gains is given by

$$\begin{aligned} u_1^+ &= \beta [(1 - p)x_1 + p\alpha x_1] \\ &= \beta [1 - p(1 - \alpha)] x_1 \end{aligned}$$

Analogously, the utility for losses is given by

$$\begin{aligned} u_1^- &= \beta [(1 - p)(-x_1) + p(1 + \alpha)(-x_1)] \\ &= \beta [1 - p + p(1 + \alpha)] (-x_1) \\ &= \beta [1 + p\alpha] (-x_1) \end{aligned}$$

Note that these formulations are special cases of modeling the cost of keeping track with a proportional penalty discussed in Section 3.2. Thus, the results obtained in this section continue to hold when we combine the probability of forgetting with a proportional cost of keeping track.

4 General formulation

The previous discussion used linear utility to simplify the exposition. In the following, I show that these results hold for any monotonically increasing, concave utility function. The sole exception is Proposition 9, which only holds for the special case of linear utility.

Assume that agents have a utility function $u(\cdot)$ which is continuous, twice differentiable for $x \neq 0$, monotonically increasing, concave, symmetric around $u(0)$, and $u(0) = 0$.

Gains For gains, the utility of acting in period 0 is:

$$u_0^+ = u(x_0) \tag{11}$$

The utility of acting in period 1 is:

$$u_1^+ = \beta u(x_1 - c) \tag{12}$$

The condition for preferring to act in period 1 is:

$$u(x_1 - c) > \frac{u(x_0)}{\beta} \tag{13}$$

Losses The utilities of acting on losses in periods 0 and 1, respectively, are as follows:

$$u_0^- = u(-x_0) = -u(x_0) \tag{14}$$

$$u_1^- = \beta u(-x_1 - c) = -\beta u(x_1 + c) \tag{15}$$

In each of these expressions, the second inequality holds by symmetry of $u(\cdot)$ around $u(0)$.

The condition for acting in period 1 is again given by $u_1 > u_0$, which simplifies to:

$$u(x_1 + c) < \frac{u(x_0)}{\beta} \tag{16}$$

Proposition 10. *Steeper discounting of gains: With a positive cost of keeping track, agents discount future gains more steeply than otherwise.*

	1. Cost is lump sum	2. Cost is fraction of original payoff
Immediate utility (gains)	$u_0^+ = x_0$	$u_0^+ = x_0$
Immediate utility (losses)	$u_0^- = -x_0$	$u_0^- = -x_0$
Delayed utility (gains)	$u_1^+ = \beta(x_1 - c)$	$u_1^+ = \beta(1 - \alpha)x_1$
Delayed utility (losses)	$u_1^- = \beta(-x_1 - c)$	$u_1^- = \beta(1 + \alpha)(-x_1)$
Basic condition (gains)	$x_1 > \frac{x_0}{\beta} + c$	$x_1 > \frac{x_0}{\beta(1 - \alpha)}$
1. More discounting of gains	Yes	Yes
	$\frac{\partial u_1^+}{\partial c} < 0$	$\frac{\partial u_1^+}{\partial \alpha} < 0$
2. Less discounting of losses	Yes	Yes
	$\frac{\partial u_1^-}{\partial c} < 0$	$\frac{\partial u_1^-}{\partial \alpha} < 0$
3. Pre-crastination	Yes	Yes
	$-\bar{x} > \beta(-\bar{x} - c)$ $c > \frac{1 - \beta}{\beta}\bar{x}$	$-\bar{x} > \beta(1 + \alpha)(-\bar{x})$ $\alpha > 1 - \beta$
4. Sign effect	Yes	Yes
	$ \beta(-x_1 - c) = \beta(x_1 + c)$ $> \beta(x_1 - c)$	$ \beta(1 + \alpha)(-x_1) = \beta(1 + \alpha)x_1$ $> \beta(1 - \alpha)x_1$
5. Loss aversion	Yes	Yes
	see above	see above
6. Magnitude effect	Yes	No
	$x_1 > \frac{x_0}{\beta} + \frac{c}{A}$	$\beta(1 - \alpha)Ax_1 > Ax_0$
7. Decreasing impatience	Yes	Yes
	$x_1 > \frac{x_0}{\beta}$	$u_1^+ = \beta(1 - \alpha)x_0$ $u_2^+ = \beta^2(1 - \alpha)x_1$ $x_1 > \frac{x_0}{\beta}$
8. Andreoni-Sprenger 1	Yes	No
(less discounting)	$U(\bar{x} + x_0, \bar{x}) = \bar{x} + x_0$ $+ \beta(\bar{x} - c)$ $U(\bar{x}, \bar{x} + x_1) = \bar{x}$ $+ \beta(\bar{x} + x_1 - c)$ $x_1 > \frac{x_0}{\beta}$	$U(\bar{x} + x_0, \bar{x}) = \bar{x} + x_0$ $+ \beta(1 - \alpha)\bar{x}$ $U(\bar{x}, \bar{x} + x_1) = \bar{x}$ $+ \beta(1 - \alpha)(\bar{x} + x_1)$ $x_1 > \frac{x_0}{\beta(1 - \alpha)}$
9. Andreoni-Sprenger 2	Yes	No
(less hyperbolicity)	$U(0, \bar{x} + x_0, \bar{x}) = \beta(\bar{x} + x_0 - c)$ $+ \beta^2(\bar{x} - c)$ $U(0, \bar{x}, \bar{x} + x_1) = \beta(\bar{x} - c)$ $+ \beta^2(\bar{x} + x_1 - c)$ $x_1 > \frac{x_0}{\beta}$	$U(0, \bar{x} + x_0, \bar{x}) = \beta(1 - \alpha)(\bar{x} + x_0)$ $+ \beta^2(1 - \alpha)\bar{x}$ $U(0, \bar{x}, \bar{x} + x_1) = \beta(1 - \alpha)\bar{x}$ $+ \beta^2(1 - \alpha)(\bar{x} + x_1)$ $x_1 > \frac{x_0}{\beta}$

Table 1: Summary of results

Proof. From 12, it is easy to see that $\frac{\partial u_1^+}{\partial c} < 0$. Thus, agents discount future gains more steeply the larger the cost of keeping track. \square

Proposition 11. *Shallower discounting of losses: With a positive cost of keeping track, agents discount future losses less steeply than otherwise.*

Proof. As above, it follows from 15 that $\frac{\partial u_1^-}{\partial c} < 0$. Thus, the disutility of future losses increases in c , i.e. future losses are discounted less as the cost of keeping track rises. \square

Proposition 12. *Pre-crastination: When agents choose between an equal-sized immediate vs. delayed loss, they prefer to act in period 1 when the cost of keeping track is zero, but may prefer to “pre-crastinate” if with a positive cost of keeping track.*

Proof. When the payoffs of acting now vs. acting later are both $-\bar{x}$, and $c = 0$, the condition for acting later on losses given in equation 16 simplifies to $u(\bar{x}) < \frac{u(\bar{x})}{\beta}$, which is always true with $\beta < 1$. Thus, when agents choose between equal-sized immediate vs. delayed losses and $c = 0$, they prefer to act in period 1. However, when $c > 0$, agents may prefer to act in period 0: the condition for acting in period 0 implied by 14 and 15 is $u(-\bar{x}) > \beta u(-\bar{x} - c)$, which simplifies to

$$\frac{u(\bar{x})}{u(\bar{x} + c)} < \beta$$

Because $0 \leq \frac{u(\bar{x})}{u(\bar{x} + c)} < 1$ and $\frac{\partial \frac{u(\bar{x})}{u(\bar{x} + c)}}{\partial c} < 0$, with a sufficiently large cost of keeping track and sufficiently small β , this condition can be met. In this case, agents prefer to incur the loss in period 0 rather than period 1, i.e. they “pre-crastinate”. \square

Proposition 13. *Sign effect: With a positive cost of keeping track, agents discount gains more than losses.*

Proof. I show that the absolute value of the utility of a delayed loss is greater than that of a delayed gain, which corresponds to greater discounting of gains than losses. By symmetry of $u(\cdot)$ around $u(0)$, the absolute value of the utility of a delayed loss is

$$|u_1^-| = |\beta u(-x_1 - c)| = \beta u(x_1 + c)$$

Because $u_1^+ = \beta u(x_1 - c)$ and $u'(\cdot) > 0$, it is easy to see that $|u_1^-| > u_1^+$. Thus, the absolute value of the utility of a delayed loss is greater than that of a delayed gain. \square

Proposition 14. *Loss aversion: With a positive cost of keeping track, agents exhibit loss aversion for future outcomes.*

Proof. Follows directly from Proposition 13. \square

Proposition 15. *Magnitude effect: With a positive cost of keeping track, agents discount large amounts less than small amounts.*

Proof. The magnitude effect requires that the discounted utility of a large payoff Ax ($A > 1$) be larger, in percentage terms relative to the undiscounted utility of the same payoff, than that of a smaller payoff x :

$$\frac{\beta u(Ax - c)}{u(Ax)} > \frac{\beta u(x - c)}{u(x)}$$

By concavity of $u(\cdot)$, and given that $A > 1$,

$$u(Ax + c) - u(Ax) < u(x + c) - u(x)$$

Because $u(\cdot)$ is monotonically increasing, $u(Ax) > u(x)$, and therefore:

$$\frac{u(Ax + c) - u(Ax)}{u(Ax)} < \frac{u(x + c) - u(x)}{u(x)}$$

Adding one on both sides and decreasing the arguments by c :

$$\frac{u(Ax)}{u(Ax - c)} < \frac{u(x)}{u(x - c)}$$

Inverting the fractions and multiplying both sides by β , we obtained the desired result. \square

Proposition 16. *Decreasing impatience and preference reversals: With a positive cost of keeping track, agents exhibit decreasing impatience and time-inconsistent preference reversals.*

Proof. When both outcomes are moved one period into the future, they are both subject to the risk and penalty of forgetting; their utilities are:

$$u_1 = \beta u(x_0 - c)$$

$$u_2 = \beta^2 u(x_1 - c)$$

The condition for acting later is

$$u(x_1 - c) > \frac{u(x_0 - c)}{\beta}$$

Note that, because $u(\cdot)$ is monotonically increasing and therefore $u(x_0 - c) < u(x_0)$, this condition is easier to meet than condition 13 for choosing between acting immediately vs. next period, which is $u(x_1 - c) > \frac{u(x_0)}{\beta}$. Thus, when both outcomes are delayed into the future, impatience decreases. \square

Proposition 17. *Andreoni-Sprenger convex budgets, Effect 1: With a positive cost of keeping track, agents exhibit less discounting when adding money to existing payoffs than otherwise.*

Proof. Assume a fixed initial payoff \bar{x} in both periods 0 and 1. The lifetime utility of the agent in the absence of other transfers is

$$U(\bar{x}, \bar{x}) = u(\bar{x}) + \beta u(\bar{x} - c)$$

Now consider how this utility changes after adding x_0 in period 0 or x_1 in period 1:

$$U(\bar{x} + x_0, \bar{x}) = u(\bar{x} + x_0) + \beta u(\bar{x} - c)$$

$$U(\bar{x}, \bar{x} + x_1) = u(\bar{x}) + \beta u(\bar{x} + x_1 - c)$$

The condition for acting later is $U(\bar{x}, \bar{x} + x_1) > U(\bar{x} + x_0, \bar{x})$, which we rearrange as

$$u(\bar{x} + x_0) - u(\bar{x}) < \beta u(\bar{x} + x_1 - c) - \beta u(\bar{x} - c)$$

By the concavity of $u(\cdot)$, we have

$$\beta u(\bar{x} + x_1 - c) - \beta u(\bar{x} - c) < \beta u(x_1) + \beta u(\bar{x} - c) - \beta u(\bar{x} - c) = \beta u(x_1)$$

It follows that

$$u(\bar{x} + x_0) - u(\bar{x}) < \beta u(x_1)$$

Recalling that the original condition is $u(x_1 - c) > \frac{u(x_0)}{\beta}$, we reduce the arguments by c and rearrange:

$$u(x_1 - c) > \frac{u(x_0 + \bar{x} - c) - u(\bar{x} - c)}{\beta}$$

We distinguish three cases:

1. If $c < \bar{x}$, then $\bar{x} - c > 0$ and this condition is less strict than the original condition, $u(x_1 - c) > \frac{u(x_0)}{\beta}$. Agents thus exhibit less discounting when money is added to existing payoffs than otherwise.
2. If $c = \bar{x}$, then $\bar{x} - c = 0$ and this condition is equivalent to the original condition.
3. If $c > \bar{x}$, then $\bar{x} - c < 0$ and this condition is stricter than the original condition. In this case, agents exhibit more discounting when money is added to existing payoffs than otherwise.

Note that if $c > \bar{x}$, the cost of keeping track c exceeds the fixed initial payoff \bar{x} . Under these circumstances, the agent would not initially have chosen to receive the fixed initial payoff and instead preferred to not receive money at the timepoint in question; put differently, she would have forgone the opportunity. Thus, when money is added to existing payoffs, it must be the case that $c \leq \bar{x}$. This proves the proposition. \square

Finally we ask whether agents exhibit less hyperbolic discounting when money is added to existing payoffs and the utility function is concave. This is the only result that holds with linear utility, but does not hold with concave utility. In fact, with concave utility, agents exhibit *more* hyperbolicity when money is added to existing payoffs than otherwise.

Proposition 18. *Andreoni-Sprenger convex budgets, Effect 2: With a positive cost of keeping track, agents exhibit more hyperbolic discounting when adding money to existing payoffs.*

Proof. Recall the case with no fixed initial payoff \bar{x} . The condition for acting in period 1 over period 0 is

$$(1) \quad \beta u(x_1 - c) > u(x_0) \tag{17}$$

When both periods are in the future, the condition for acting in period 2 over period 1 is

$$(2) \quad \beta u(x_1 - c) > u(x_0 - c) \tag{18}$$

Note that condition 17 is less strict than condition 18; this implies hyperbolic discounting, as the condition for acting in the future is easier to meet when both periods are in the future than when one is in the present.

Now assume a fixed initial payoff \bar{x} in both periods. The condition for acting in period 1 over period 0 is

$$(3) \quad u(\bar{x}) + \beta u(\bar{x} + x_1 - c) > u(\bar{x} + x_0) + \beta u(\bar{x} - c) \tag{19}$$

When both periods are in the future, the condition for acting in period 2 over period 1 is

$$(4) \quad u(\bar{x} - c) + \beta u(\bar{x} + x_1 - c) > u(\bar{x} + x_0 - c) + \beta u(\bar{x} - c) \tag{20}$$

Rearranging 19 and 20, we obtain:

$$(5) \quad u(\bar{x} + x_0) - u(\bar{x}) < \beta u(\bar{x} + x_1 - c) - \beta u(\bar{x} - c) \tag{21}$$

$$(6) \quad u(\bar{x} + x_0 - c) - u(\bar{x} - c) < \beta u(\bar{x} + x_1 - c) - \beta u(\bar{x} - c) \quad (22)$$

We have $c > 0$ by assumption. Therefore, by the concavity of $u(\cdot)$, $u(\bar{x} + x_0) - u(\bar{x}) < u(\bar{x} + x_0 - c) - u(\bar{x} - c)$. Thus, condition 22 is stricter than condition 21. Agents therefore discount more steeply in the future compared to the present when money is added to existing payoffs (i.e., the opposite of hyperbolic discounting).

We further note that conditions 21 and 22 are equivalent when $c = 0$ or when the utility function is linear. Indeed, the resulting lack of hyperbolic discounting in these special cases shown here is in line with the corresponding propositions proved above. \square

5 Applications

The framework described above unifies a number of anomalies that are observed in discounting behavior in the lab and the field. In addition, the framework speaks to a number of findings in development economics, which I briefly summarize here.

5.1 Chlorinating water at the source vs. the home

In many developing countries, access to clean water is difficult. Many households fetch water from a distant water source, where it is often contaminated. Purification through chlorination is relatively easy and cheap, but Kremer et al. (2009) show that chlorination levels in Kenya are low. In addition, providing households with free bottles of chlorine that they can keep in the home and use to treat water have little effect on chlorination levels. However, a slightly different intervention was much more successful: when Kremer and colleagues equipped the water source where people fetched the water with chlorine dispensers – simple containers from which individuals can release enough chlorine to treat the water they fetch at the source – the prevalence of chlorination increased dramatically. This finding can be explained in the framework described above: when an individual is at a water source and considers whether or not to chlorinate water now – i.e. while still at the source – or later – i.e., after returning to the homestead – she previously had no real choice: chlorination was not available at the source, and “later” was the only option. In practice, once she returned to the household, she would often have forgotten her plan to chlorinate water, and would therefore not do it. In contrast, the chlorine dispenser at the source fulfills two functions. First, it reminds individuals about the chlorination and its benefits; second, it provides an opportunity to act immediately and thereby save the cost of keeping track. Thus, the model predicts that households may prefer to perform the (probably cumbersome) task of chlorinating water sooner rather than later, in the knowledge that a decision to do it later might cause it to be forgotten altogether.

5.2 Nudging farmers to use fertilizer

Developing economies are often characterized by surprisingly low levels of adoption of profitable technologies. A prime example is agricultural fertilizer, which is widely available and affordable in countries such as Kenya, and increases yields substantially. Nevertheless, few farmers report using fertilizer, even though many report *wanting* to use it. Duflo et al. (2009) show that a simple intervention can substantially increase fertilizer use: by offering timed discounts on fertilizer to farmers immediately after the harvest (when liquidity is high), rather than before the next planting season (when fertilizer would normally be bought, but liquidity is low), Duflo and colleagues provided farmers with both a reminder of their desire to use fertilizer, as well as with an opportunity to act immediately. As in the chlorine example, buying fertilizer is an expense, and therefore, assuming constant prices, standard discounting models would predict that farmers should delay it as much as possible. However, in Duflo et al.'s study, farmers procrastinate because they anticipate that they will fail to buy fertilizer with a non-zero probability if they delay it. This cost of keeping track is somewhat different than those discussed above – in particular, it is unlikely to stem from forgetting because the need to purchase fertilizer probably becomes ever more salient as the planting season approaches. Instead, it is likely that keeping track in this case consists of keeping track of the income from the last harvest and avoiding to spend it on other goods, with the result that nothing is left to buy fertilizer before the planting season.

5.3 Getting children vaccinated

Many children in developing countries do not receive the standard battery of vaccinations, even when these vaccinations are safe and available free of charge. Banerjee et al. (2010) organized and advertised immunization camps in 130 villages in rural India, to which mothers could bring their children to have them immunized. In a subset of villages, mothers additionally received a small incentive when they brought their children to get vaccinated. Banerjee and colleagues find that vaccination rates increase dramatically as a result of this program. Interpreted in the framework presented in this paper, we might suspect that women remember at random times that they value vaccinations and want to get their children vaccinated. However, these thoughts may often occur when no good opportunity exists to act on the thought – e.g., while performing other work, or at night. The vaccination camps might combine a reminder of the desire to get children vaccinated with a concrete opportunity to follow through on this desire.

5.4 Reminders to save

The savings rates of the poor are generally low, despite the fact that they often have disposable income that could in principle be saved. Karlan et al. (2010) show that savings rates among poor individuals in the Philippines, Peru, and Bolivia can be substantially increased through simple text message (SMS) reminders to save. This finding confirms that the poor in fact do have disposable

income which they can save, and that they have a desire to do so. The fact that reminders alone can make them more successful in reaching this goal suggests that they may on occasion simply forget their savings goal and instead spend on other goods. The reminders transiently reduce the cost of keeping track to zero and thus allow households to follow through on their goal.

Note that the model predicts that reminders work because they decrease the cost of keeping track: if an individual is credibly offered a reminder, her cost of keeping track is reduced, so she is more likely to wait and successfully perform the task. However, the model also predicts that timing is crucial: if a reminder comes at a time when the agent can act on it, the probability that it is successful should be very high. In contrast, when the agent currently cannot act on it, the agent is in the previous situation of having to make a plan to act on the reminder later, making it less likely to happen because of the cost of keeping track.

5.5 Status quo bias, default choice, and technology adoption

The phenomenon that people stick to defaults can be explained in the same framework. As pointed out above, tasks and opportunities arise at random points in time; this includes thoughts such as “I should really get a 401k”. The model predicts that people are much less likely to act on such thoughts when they occur at times where acting on them immediately is not possible. In such cases, the agents make plans to act on the thought in the future, but these plans are subject to the cost of keeping track and therefore less likely to be implemented. Examples include the tendency to stick to defaults in organ donation and retirement plan decisions. Another prominent example is the failure to adopt profitable technologies often found in developing countries; this phenomenon is a special case of default choice, and is also captured by the model.

6 Conclusion

This paper has argued that a number of features of empirically observed discount functions can be explained with a lump-sum cost of keeping track of future transactions. First, such a cost will cause agents to discount the future more than they otherwise would; for instance, agents whose time preference coincides with the interest rate will exhibit behavior that appear much more impatient with a positive cost of keeping track. Second, if the cost is constant across time, agents will exhibit decreasing impatience, i.e. they will discount the near future more than the distant future. Third, if the cost is lump-sum, agents will also exhibit a magnitude effect, i.e. they will discount smaller payoffs more heavily than larger payoffs. Fourth, because the cost of keeping track is subtracted from gains, but is also subtracted from losses, the model produces a sign effect: a loss is discounted less than a gain of equal magnitude, both because the gain is less attractive due to the cost of keeping track than otherwise, and because the loss is more painful due to the cost of keeping track. Fifth, this result of the model also implies loss aversion for future outcomes, which is a

hallmark of prospect theory (Kahneman & Tversky, 1979). Sixth, the magnitude effect also implies that agents exhibit less discounting when money is added to existing payoffs in the present and the future, and that agents exhibit no decreasing impatience under these circumstances; this finding has recently been empirically confirmed by Andreoni & Sprenger (2012). Seventh, the model predicts pre-crastination: when the cost of keeping track is large enough, agents will prefer to incur losses sooner rather than later. For instance, they may prefer to get a bill payment out of the way if they anticipate a risk of forgetting about the payment (and an associated penalty) in case they postpone it. This phenomenon is familiar from everyday experience, but is currently not captured by discounting models. Pre-crastination has also recently been empirically confirmed (Rosenbaum et al., 2014). Eighth, the model also predicts status quo bias and the choice of defaults: agents may appear to be unwilling to adopt profitable technologies or stick to disadvantageous defaults despite the presence of superior alternatives. The model suggests that these behaviors need not reflect preferences, but either an inability to act on such opportunities at the time when individuals think about them (e.g. no chlorine dispenser at the source while fetching water), or, in the case where the cost of keeping track is small enough that agents make plans to act later, the risk of forgetting to act on the opportunity (forgetting to chlorinate water in the home after returning from the water source). Finally, the model predicts that simple reminders might cause individuals to act on opportunities that they previously appeared to dislike, and that reminders and/or creation of opportunities to act on tasks, such as bill payments, loan repayments, or taking medication, will increase payment reliability and adherence. Indeed, a number of studies have shown positive effects of reminders on loan repayment (e.g. Karlan et al., 2010).

A limitation of the current model is that it predicts that only sophisticates will exhibit the anomalous discounting behaviors summarized above, while naïve types will exhibit exponential discounting. To be sure, this leads to a welfare loss for the naïve type if they underestimate their probability of forgetting future tasks and opportunities and therefore are more likely to incur the associated penalties; but it generates the somewhat surprising prediction that sophisticated decision-makers will appear more “anomalous” in their discounting behavior than naïve types.

Together, these results unify a number of disparate features of empirically observed discounting behavior, as well as behavior of individuals in domains such as loan repayment, medication adherence, and technology adoption. The model makes quantitative predictions about the effectiveness of reminders, which should be experimentally tested.

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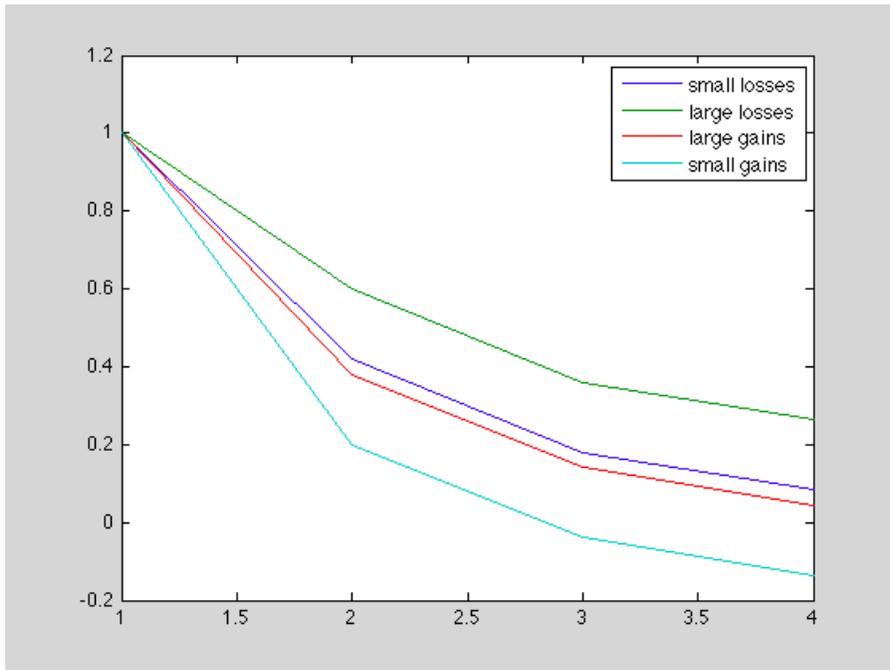


Figure 1: A lump-sum cost of keeping track of future transactions produces hyperbolic discounting with a magnitude effect and a sign effect. In this example, gains and losses of \$10 and \$100 are discounted with $\beta = 0.4$ and a lump-sum cost of keeping track of \$2. Note that gains are discounted more than losses, and large payoffs are discounted less than small payoffs.