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"Can We Really Observe Hyperbolic Discounting?"

by

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Can We Really Observe Hyperbolic Discounting?*

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Abstract

This paper proposes a new, more robust, experiment to test for the presence of hyperbolic discounting. Recently, a growing literature has studied intertemporal choice when individuals discount the future hyperbolically. These preferences generate dynamically inconsistent choices, in contrast with the usual assumption of exponential discounting, where this issue cannot arise. Hyperbolic discounting is justified based on experimental evidence of individual self-control problems. We argue that this interpretation depends crucially on the absence of uncertainty. We show that, once uncertainty is included, the observed behavior is compatible with exponential discounting. We then test for the presence of hyperbolic discounting in a new experiment that controls for uncertainty. The experiment offers two choice sets, the second being a strict subset of the first. Exponential discounters will (possibly weakly) prefer the largest one. Hyperbolic discounters, in contrast, will (strictly) prefer the second set because its design makes it equivalent to a commitment technology. The experiment is conducted on a sample of undergraduate students. Our results suggest that hyperbolic behavior is more difficult to find than implied by previous experiments.

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1. Introduction

Recently, a growing literature has concentrated on the study of the dynamic choices of individuals that discount over short horizons at a higher rate than over long horizons. This feature is known as hyperbolic discounting. Examples of this literature include Barro (1999), Diamond and Kőszegi (2002), Harris and Laibson (2001), Gul and Pesendorfer (2001), Jovanovic and Stolyarov (2000), Laibson (1997) and O'Donoghue and Rabin (1999) among many others. These papers explore a particular characteristic of this kind of discounting, its inducement of dynamically inconsistent choices as defined by Strotz (1955): if individuals have the opportunity to revise their plans in the future, they will deviate from their original choices.

This inconsistency changes the behavior of agents with respect to the predictions of standard theory. In particular, it is argued that hyperbolic discounting can account for issues such as addictions or life cycle consumption patterns that are difficult to explain within the traditional framework (see Akerlof (1991), Becker and Murphy (1988) or Laibson *et al.* (1998)). Moreover, these models have important policy implications. For instance, one of their predictions is that if we substitute our current pay-as-you-go social security system by one based on private retirement accounts, we may lower welfare since, under the new rules, dynamically inconsistent consumers will undersave (see Imrohoroğlu *et al.* (2000)).

The principal piece of evidence presented to support hyperbolic discounting is a common anomaly observed in experiments as reported by Loewenstein and Thaler (1989), Loewenstein and Prelec (1992) and Ainslie (1991). When confronted with the choice between two payments that are close in time (for example \$10 today *versus* \$11 tomorrow), a share of the population prefers the immediate payment, even if that implies an incredibly high discount rate (in this case $7.79\exp(-16)$ on an annual basis). However, most of the agents choose \$11 in 101 days over \$10 in 100 days, even if the distance between both payments is still one day.

The proposed explanation for this behavior is that individuals discount the future hyperbolically, with a much greater discount rate in the short-run than in the long-run. Given this changing discounting they prefer \$10 today and \$11 in one hundred days. Either a generalized hyperbola $(1+\alpha t)^{-\frac{\gamma}{\alpha}}$ with α, $\gamma > 0$ or the more tractable quasi-hyperbola $\delta\beta^t$, with β, $\delta < 1$, are recommended as the appropriate modeling choices to discount events at time t.

This paper makes two points. First, it presents an alternative explanation for the de-

scribed anomaly: *uncertainty*. When we face a payment today against a payment tomorrow, uncertainty's role is asymmetric. It matters when we evaluate the payment tomorrow but it does not when we assess the payment today since the realizations of all shocks (in preferences, endowments or technology) are already known. However, when the decision involves two future payments, uncertainty is relevant for both of them. Thus both choice problems are not equivalent. We show then how even a small degree of uncertainty generates the observed behavior in a standard model with exponential discounting. If uncertainty can also induce the choices reported in experiments, the existing evidence is not conclusive about how agents discount over time.

The second point of the paper is to propose an experiment to test for the presence of hyperbolic discounting that controls for uncertainty. The new experiment offers two choice sets, the second being a strict subset of the first. Exponential discounters will always (possibly weakly) prefer the largest one. Hyperbolic discounters, in contrast, will (strictly) prefer the second set because its design makes it equivalent to a commitment technology that allows them to overcome their problem of temporal inconsistency. The experiment is conducted on a sample of undergraduate students. The results imply that hyperbolic behavior is much more difficult to find than suggested by previous experiments.

This finding is also a remainder of a well-known fact: the need to carefully design our experiment to control for the resulting confounding effects implied by the theory. This concern is crucial for us since we provide an alternative and new explanation for the evidence in the literature. We now discuss three of these confounding effects.

The first effect is learning, specially the learning of the experiment instructions. There is some evidence that we observe convergence towards behavior implied by standard theory when experiments are repeated on the same population (Miller, Rust and Palmer (1994)). In the same line, Friedman (1998), building on Gigerenzer (1991), claims that each choice "anomaly" can be greatly diminished or entirely eliminated in appropriately structured learning environments. In the context of intertemporal choice, learning is relevant because some of the experiments devised to detect hyperbolic discounting use relatively sophisticated mechanisms, such as second-bid auctions, to elicit responses (see Horowitz (1991) and Kirby (1997)). We read the evidence from these experiments as joint tests of the subjects' preferences and of their understanding of the rules of the experiment. In comparison, our set-up only involves, as described below, an extremely simple choice problem.

The second effect is the existence of outside trading opportunities. An example is described by Mulligan (1996). In an economy with financial markets, the relevant parameter for the choice problems above is not the discount factor but the interest rate since thanks to financial intermediation agents can rearrange their cash flow into an optimal consumption stream. Thus, an alternative (although unlikely) explanation for the outcome of the experiments on hyperbolic discounting involving monetary payments could be the subjects' lack of knowledge of the arbitrage possibilities offered by financial markets. We can take this example further and argue that if we assume that access to financial markets is limited, the relevant quantity is not anymore the discount factor but the (unobservable) ratios of marginal utilities evaluated at the constrained consumption levels. Again the existing experimental evidence involving money lacks a clear interpretation. To avoid this problem, we design an experiment in which subjects do not choose between two different amounts of money but between goods for which intertemporal trading is not feasible.

The third factor, and the one we emphasize the most in this paper, is uncertainty. Standard economic theory predicts different behavior with and without it. Operationalizing the theory in the laboratory may introduce uncertainty in subtle ways, and this in turn may change the predicted behavior of the experimental subject. We design our experiment to explicitly account for a specific form of uncertainty faced by subjects. We show how this control can be key for the interpretation of the experimental evidence and how it can reverse the burden of the proof against hyperbolic discounting.

The rest of the paper is structured as follows. Section 2 presents a simple model of dynamic choice with uncertainty. Section 3 describes the experiment. Section 4 reports the experimental results. Section 5 compares our results with those in the literature and section 6 concludes. An appendix includes the instructions of the experiment.

2. A Model with Uncertainty

Consider an economy with a continuum of agents of measure 1. Each agent has preferences over sequences of consumption representable by a utility function of the form:

$$\max_{\{c_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t E_0 U\left(A_t c_t\right) \tag{1}$$

where c_t is the consumption at period t, β is the discount factor and $A_t \in (0, \infty)$ is an idiosyncratic shock to preferences, revealed at the beginning of each period before consumption decisions are made, with an independent across time L_2-distribution P over the Borel σ-field of subsets of $\Re_+$, ϕ, such that $P(\Upsilon) > 0$ for all sets $\Upsilon \subseteq \phi$. E_0 is the conditional expectation operator evaluated at time 0 given P. We will assume that the population follows a law of large numbers (Uhlig (1996)). The period utility function satisfies the usual properties: $U(\cdot) \in C^2$, $U'(\cdot) > 0$, $U''(\cdot) < 0$ for all c_t in $\Re_+$. Further, $U(\cdot)$ is bounded below at 0.

Given these assumptions, the following lemma holds:

Lemma 1. *$\int U(A_t c_t)\, dP$ is bounded for all c_t in $\Re_+$.*

Proof. Since P is L_2, for a given c_t, $\int A_t c_t dP < \infty$. As $U''(\cdot) < 0$, by the Hyperplane Separation Theorem there are some constants a and b such that $U(A_t c_t) \leq a A_t c_t + b$. Then $\int U(A_t c_t)\, dP \leq a \int A_t c_t dP + b < \infty$. ■

From Lemma 1 the maximization problem is well defined and the usual theorems in choice theory follow easily.

We will show how agents in this economy behave differently when faced with apparently similar situations. In particular we study the case when agents face the following two choice problems:

1. Consume c' units of the good in n periods or c'' units of the good in $n+1$ periods.

2. Consume c' units of the good today or c'' units of the good tomorrow.

Finally we assume these consumptions units are non tradable (and thus there is no possibility of insurance among agents) and that the agent does not have any other source of income. The following proposition is direct.

Proposition 2. *All the agents will prefer the same option in the choice problem 1.*

Proof. First note that, for every agent, the utility of consuming at time n is given by $\beta^n \int U(A_n c')\, dP$ while the utility of consuming at time $n+1$ is given by $\beta^{n+1} \int U(A_{n+1} c'')\, dP$. By Lemma 1 both expressions are bounded constants and by the independence assumption of the shocks, they have the same value for all consumers in the economy regardless of A_0. Then all agents will opt for consumption in the same period. ■

Without loss of generality assume that the consumption units in the choice problem 1 is such that:

$$\beta \int U\left(A_{n+1}c''\right) dP > \int U\left(A_n c'\right) dP$$

Then, all agents will wait until period $n+1$, as observed in experiments. Now, we can prove the next proposition.

Proposition 3. *Different agents will take different options in the choice problem 2.*

Proof. For every agent, the utility of consuming at time 0 is $U\left(A'c'\right)$ where A' is the realization of the preferences shock at time 0, while the utility of consuming at time 1 is $\beta \int U\left(A_1 c''\right) dP$.

It follows from our assumption that $U(\cdot)$ is invertible. Then there exist an A^*:

$$A^* = \left(U^{-1}\left(\beta \int U\left(A_1 c''\right) dP\right)\right) / c'$$

such that all agents with $A' \geq A^*$ will opt for consumption in period 0 and all agent with $A' \leq A^*$ will wait until period 1.

Again by assumption both $P\left([A^*, \infty)\right) > 0$ and $P\left((0,\ A^*)\right) > 0$. By the law of large numbers those measures coincide with the population measures and then with the share of realized choices. ■

Propositions 1 and 2 show that, under uncertainty, the behavior of agents is different when the choice deals only with the future and when the problem involves both the present and the future. The intuition for the result is straightforward. In choice problem 2, the agent knows for sure the utility from consuming today. If the current shock A is high enough, she would prefer to consume immediately even if the quantity of the good is substantially lower than the quantity she will obtain waiting one period. In fact, A does not need to be too high in absolute terms because she is risk-averse. In choice problem 1, since both alternatives are in the future, uncertainty gets integrated out and the only relevant factor is the comparison between the discount factor and the difference in the quantities of the good.

To illustrate this point we present a numerical example. We will consider a modified CRRA utility function:

$$U = \frac{\left(A_t c_t + \varepsilon\right)^{1-\sigma} - 1}{1-\sigma}$$

where $\varepsilon > 0$ is a real number that bounds below the utility function but small enough to be numerically irrelevant and A_t is distributed as $\log A_t \sim \mathcal{N}(1, \theta_A)$. We fix β at 0.9999 (equivalent to a 0.96 annual discount factor if we use days as our time units) and, to keep figures from the standard example, we set c' equal to 10 and c'' equal to 11.

Then, for $\sigma = 2$ and $\theta_A = 0.25$, 52% of agents prefer to consume today and all of them prefer consumption in $n+1$ over consumption in n. As shown in figure 1, even if the variance of the preference shock is reduced, a sizeable part of the population will keep this choice. For instance, with a variance of 0.04, still 36% of the population opts for present consumption. If we use higher risk-aversions, like those reported by Barsky *et al.* (1997), the results are even clearer. For $\sigma = 3$ and $\theta_A = 0.25$, 64% of the agent choose present consumption. Even with a variance as low as 0.01, this share is still 32%[1].

Is this a fair example? Are these variances plausible? It is hard to judge. However, it seems reasonable to defend the hypothesis that preferences suffer shocks over time. A simple explanation takes the utility function as a production function that produces services for the self and suffers from technology shocks. For example, the ability to appreciate a movie depends con elements such as the theater temperature or the number of people in the room. Another justification is to see the utility function as some reduced form of a more complex problem where the capacity to enjoy a good depends on the consumption of many other goods that the economist does not want to model explicitly. Nevertheless, the bottom line is simple: small changes in the utility function can parsimoniously account for the experimental findings on intertemporal choice.

3. An Alternative Experiment

The existence of an alternative to hyperbolic discounting as an explanation for the reported behavior pattern raises the need to collect more empirical evidence to distinguish between the two models of discounting.

A first, natural approach to compare the two hypotheses is to use micro data on consumption. Harris and Laibson (2001) derive Euler equations that can be used to test for hyperbolic discounting. We believe that exploring this route is difficult. The consumption

[1] For comparison purposes note that Ainslie and Haendel (1982) found that 33% of subjects made inconsistent choices when faced with real payoffs.

policy functions under subgame perfection-hyperbolic discounting and under exponential discounting tend to be close (see Laibson *et al.* (1998)). This similarity plus the poor small sample performance of moment estimators (Burnside and Eichenbaum (1996)) and the usual measurement errors of micro data make it extremely challenging to discriminate between the two alternatives explanations directly from consumption data.

We focus instead on the original source of empirical evidence regarding hyperbolic discounting: experiments on individual intertemporal choice. Given our discussion in section 2, we want to design a new, more robust experiment to detect hyperbolic discounting. We consider four points in the design. First we look for a simple experiment that subjects can understand easily. Second, all the implicit costs for every alternative are equalized so they do not distort the choice. Third, we assure that random shocks to preferences influence the choices symmetrically. Fourth we use goods without outside intertemporal markets.

With these points in mind we propose the following experiment involving minutes of access of undergraduates to videogames[2]. The agents are presented with two alternatives:

- Option A: Get 180 minutes of access to videogames that can be played in the laboratory in three consecutive days after some specified date in the future. So if the specified date is n they can use the minutes in $n+1$, $n+2$ and $n+3$. The distribution of time is constrained by the experiment to be 60 minutes on the first day, 60 minutes on the second and 60 minutes on the last day. Subjects must go to the laboratory for the experiment on all the three days and sign an attendance sheet.

- Option B: Get 180 minutes of access to videogames that can be played in the laboratory in three consecutive days after the same specified date in the future. So if the specified date is n they can use the minutes in $n+1$, $n+2$ and $n+3$. They are free to distribute that time as they wish over the three days but they should come to the laboratory for the experiment on all the three days and sign an attendance sheet.

An exponential discounting agent will always opt for the second alternative, regardless of the degree of uncertainty associated with preferences shocks. Since she is able to design

[2]The use of videogames has also been suggested by Millar and Navarick (1984).

dynamically consistent plans, she solves the value function problem:

$$V(A_t, M_t, t) = u(A_t c_t) + \beta \int V(A_{t+1}, M_{t+1}, t+1)\, dP,\ t \in \{n+1, n+2\} \tag{2}$$

$$V(A_3, M_3, 3) = u(A_3 c_3) \tag{3}$$

$$s.t.\ M_{t+1} = M_t - c_t \tag{4}$$

$$M_n = 180 \tag{5}$$

where the states are the period shock A_t, the time t and M_t are the remaining minutes to be consumed. The solution of this problem $\int \beta^{n+1} V^*(A_t, 100, 1)\, dP$ is at least as high as $\sum_{t=n+1}^{3} \beta^t E_0 U(A_t 60)$ as she can always replicate, by herself, the second alternative (the solution of an unconstrained problem is at least as high as the constrained one). In addition, in a generic case, she can rearrange the consumption stream to account for the discount factor and the uncertainty, and then:

$$\int \beta^{n+1} V^*(A_t, 100, 1)\, dP > \sum_{t=n+1}^{3} \beta^t E_0 U(60) \tag{6}$$

This result is well known and it is somehow similar to Koopmans (1964) and Kreps (1979): in the presence of uncertainty, it is rational to show a "preference for flexibility".

What will an hyperbolic discounting agent prefer? To analyze her choice, we need more structure. Assume, as in Phelps and Pollack (1968), that the total utility of consuming at times $n+1$, $n+2$ and $n+3$, evaluated at 0 is represented by:

$$V_0 = E_0 \left[U(c_0) + \delta \sum_{t=n+1}^{n+3} \beta^t E_0 U(c_t) \right] \tag{7}$$

and that the period utility function, as in the example in the last section, is:

$$U = \frac{(A_t c_t + \varepsilon)^{1-\sigma} - 1}{1-\sigma} \tag{8}$$

where $\log A_t \sim \mathcal{N}(1, \theta_A)$. The utility under option B is then just:

$$V_0^2 = \delta \sum_{t=n+1}^{n+3} \beta^t \int \frac{(A_t 60 + \varepsilon)^{1-\sigma} - 1}{1-\sigma} dP \tag{9}$$

For the first option, we find the Nash Equilibrium in the game of the agent against herself (see Laibson (1997))[3]. Using backward induction and the response functions of future selves we can find the consumption path for W total minutes available at the beginning of period $n+1$:

$$c_{n+1} = \frac{k'}{1+k'}W \tag{10}$$

$$c_{n+2} = \frac{k}{(1+k')(1+k)}W \tag{11}$$

$$c_{n+3} = \frac{1}{(1+k')(1+k)}W \tag{12}$$

where k and k' are functions of A_n, A_{n+1} and A_{n+2}.

The utility of the self at present time is then:

$$V_0^1 = \delta\beta^n \int_{A_1} \frac{\left(\frac{A_1 k'}{1+k'}W\right)^{1-\sigma} - 1}{1-\sigma} dP + \delta\beta^{n+1} \int_{A_1,A_2} \frac{\left(\frac{k}{1+k'}\frac{A_2}{1+k}W\right)^{1-\sigma} - 1}{1-\sigma} dP +$$
$$+ \delta\beta^{n+1} \int_{A_1,A_2,A_3} \frac{\left(\frac{A_3}{(1+k')(1+k)}W\right)^{1-\sigma} - 1}{1-\sigma} dP \tag{13}$$

This expression shows that there are two different forces with opposite effects. First, the self-control problem reduces utility with respect to the exponential discounting problem. Second, the lack of flexibility in option A increases the utility of option B even for hyperbolic discounters. Since this integral does not have an analytic solution, we use numerical methods to evaluate it for $\beta = 0.999$, $\delta = 0.6$ and different values of θ_A and σ (including those in our example in section 2). We found than, in general, we will have $V_0^2 > V_0^1$. Exceptions occur when the variance of the preference shock and the risk aversion are extremely high, cases where standard theory easily explains the observed preference for present consumption.

The intuition behind the design of the experiment is simple: hyperbolic discounters will trade off the higher flexibility of the first option (that allows them to compensate for shocks to preferences) for the commitment of the second one as they are aware of their self-control problem. However the exponential discounters, since they do not face temporal inconsistency, will always prefer to keep the flexibility option available. We think that the experiment embodies the idea of Gul and Pesendorfer (2001) that a hyperbolic discounter may prefer a

[3] Even if a recursive formulation of the problem is possible, here the game theoretic approach is simpler.

reduced set of alternatives to a bigger one since the smaller set is a commitment technology that increases its welfare. We also see the experiment as parallel to the analysis in Laibson (1994) where agents with self-control problems like to have access to a "binding automaton", a commitment device that restricts the freedom of choice of future selves.

Finally let us conclude summarizing the properties of the experiment:

1. It generates different behavioral predictions for exponential and for hyperbolic discounters with little external structure.

2. It controls for hidden cost: both alternatives requires that all subjects travel all three days to the laboratory and the cost is independent of the amount of minutes played each day.

3. It controls for uncertainty: moving all relevant payoffs into the future removes any possible asymmetry between the alternatives.

4. It eliminates outside markets for the consumption good being offered. Even if subjects can play video games elsewhere, there is no mechanism to exchange the minutes in the experiment with the outside alternatives.

5. It allows for a nice dual interpretation. If the subjects do not like the consumption good, they will see the 180 minutes as time of work. An hyperbolic discounter would tend to procrastinate (instead of overindulge) and to avoid having too many minutes at the last moment of the experiment, she would also prefer option A as a way of locking herself into working early.

4. Empirical Results

We conducted the proposed experiment with undergraduate students at the University of Minnesota. We recruited volunteers from three sections in intermediate microeconomics and one section in accounting. Students arrived at the laboratory on Monday, April 10th, 2000 and received instructions that are reproduced in the appendix. These instructions concluded with a short quiz five questions to check that the subjects understood the details of the experiment. After subjects had read the instructions and received answers to any questions they had, they completed their choice between option A (60 minutes each day to play videogames on

computers in the laboratory, two weeks later, on 24th, 25th and 26th of April) and option B (a total of 180 minutes to play videogames on computers in the laboratory, two weeks later, on 24th, 25th and 26th of April, to be allocated as they wish on those three days). After subjects completed their choices they were paid \$5. We reminded subjects that, even if they preferred to not use any of their allocated time on an specific day under option B, they were required to visit the laboratory and sign-in on each of the days, and if they completed all stages of the experiment they would be paid an additional \$30 on the 26th of April[4], regardless whether they have chosen option A or B.

Two weeks later subjects came to the laboratory and were given access to the computers with the videogames installed[5], according to the choices they have made on the 10th of April. We monitored subjects' use of time to insure that they did not exceed the time limits corresponding to the selected options. Subjects were paid \$30 in cash on the 26th of April.

A total of 23 subjects read the instructions and completed the choice form between option A and option B. 20 of the 23 subjects (87%) selected option B and the remaining 3 (13%) selected option A. We considered those choices as strong evidence that commitment devices were not preferred and that subjects did not seem to be worried about self-control problems[6]. Using the *Principle of Irrelevance of Stopping Rules*, we decided to stop the experiment at that point and not proceed with additional batches of students. El-Gemal and Palfrey (1996) discuss in detail the ideas behind our stopping behavior.

On a more formal basis, we conduct a Bayesian inference exercise. Given the existence of two different alternatives, the likelihood function is given by a binomial distribution on the share of the population that has exponential discounting p:

$$\mathcal{L}\left(x|\,p\right) = \binom{n}{x} p^{x}\left(1-p\right)^{n-x} \tag{14}$$

To complete our stochastic model we need a prior. We find that a flat, uniform prior on the percentage of subjects with hyperbolic discounting is a plausible and natural belief. In

[4] This amount to \$10 per hour of participation in the experiment, which was at least \$1 above the prevailing hourly wage for on-campus jobs.

[5] Four different videogames were installed in each computer of the laboratory. We selected the games from *Amazon.com* top-sellers list a week before the experiment to offer a popular and diverse choice of games.

[6] We conducted exit interviews at the end of the experiment. One of the subject that chose option A mentioned explicitly that she preferred that option because it was a commitment device for herself. That suggest to us that students to understood the trade-off they were facing.

addition, uniforms are conjugate priors for the binomial model and the posterior is distributed as a Beta with parameters $x+1$, $n-x+1$:

$$P(y) = \frac{\Gamma(n+2)}{\Gamma(x+1)\Gamma(n-x+1)} y^{x+1} (1-y)^{n-x+1} \tag{15}$$

Given the results of the experiment, our posterior distribution is a Beta with mean 0.84 and standard deviation 0.07, moments considerably far away from supporting the widespread existence of hyperbolic discounting. A graphical view of our empirical results is included as Figure (2), that plots our prior, our posterior and the likelihood function (up to a constant factor). We see our choice of prior as being very conservative. The uniform prior gives a lot of mass to regions around 0 that seem well below what any experiment has found as the percentage of the population choosing hyperbolically[7].

5. Comparison with Previous Results

Our empirical results suggest that the evidence in favor of hyperbolic discounting is weaker than previously claimed in the literature. Several differences in the design of our experiment may account for the alternative outcomes.

We see the existence of real rewards as one of the main reasons for these differences. Most experiments presented in the literature only involved hypothetical choices (as in Thaler (1981) or Benzion *et al.* (1989)). This hypothetical nature raises the issue of the robustness of the findings under real payoffs: individuals may not have any incentive to give a reasonable answer or even to spend mental resources to think about their true preference. There is mixed evidence and a fair degree of controversy about the interpretation of evidence coming from experiments with hypothetical payoffs.

We are only aware of a handful of experiments with real money payoffs. Although is beyond the scope of this paper to proceed to a formal meta-analysis of this literature, we believe that those experiments also offer by themselves much weaker evidence in favor of hyperbolic discounting than sometimes argued.

Ainslie and Haendel (1982) found that around a third of subjects prefer a present monetary

[7] For completeness note that the Maximum Likelihood estimate of p is, of course, 0.87 with asymptotic standard error of 0.03. Consequently, the interpretation of these results from a classical perspective is nearly identical.

payoff when confronted with a 25% interest rate over three days[8]. Holcomb and Nelson (1992) found weak evidence in favor of hyperbolic discounting when they asked undergraduate students if they preferred immediate or delayed payoffs. In the classical example of the choice between a quantity of money today and a different quantity tomorrow (with a 1.5% and 3.0% a day interest rates), between 80% and 47% of subjects choose the immediate payoff, well within what can be accounted with a model of exponential discounters with uncertainty if we do not allow financial markets. Horowitz (1992) tested for temporal consistency in the choice of risky assets. He found important differences in choice over time but neither were they systematic nor did they imply a change at the aggregate level. However, his definition of consistency (plans are equal to actual actions) cannot identify hyperbolic discounting if we use subgame perfection as our solution concept. Further, one could point to three features of his experiment: the amount of the payment was quite small (the expected value was between \$1 and \$2), subjects were not reminded of their own original choices when they made their second choice and there could have been uncontrolled changes in the financial position of subjects in the interim. These features introduce, in our opinion, a degree of noise in the experiment, and make us reluctant to draw strong conclusions from the data.

Horowitz (1991) tried to elicit directly the discount rate through a second-price auction of a bond. However the very odd behavior of subjects (they paid more for a two month bond than for a one month bond) points out important experiment design problems, some of which could be attributed to subjects' lack of familiarity with the institution. Kirby (1997) also used the idea of auctioning bonds of future payments and found more robust evidence in favor of hyperbolic discounting. However, he did not provide any procedure to distinguish between possible anomalies in the auction by itself and in the intertemporal choice problem. In fact, for the numbers of bidders that he uses (3 or 4), Kagel, Levin and Harstad (1995) have found that bidders earn positive average profits, making difficult to elicit the true values for the agents of the bond and weakening his evidence in favor of hyperbolic discounting.

In any case we should remember that all these experiments use direct money reward schemes. As discussed above this procedure does not seem the best practice. People bidding for bonds well below their market price can as easily be interpreted as subjects that discount

[8] They comment that this choice was despite the fact that the subjects have very little money available. We interpret that fact as a problem of the test, not as a reinforcing mechanism: the standard intertemporal choice model has very different predictions when liquidity constraints are binding.

hyperbolically than as subjects with a hyperbolically distributed prior over the probability of default on the bond by the experimenter.

Finally, we should mention a limitation of our experiment that can also explain some of the differences with other results. With its present design, the experiment is unable to separate exponential discounters from naive hyperbolic discounters. These last ones, in the language of O'Donoghue and Rabin (1999), have hyperbolic preferences but do not foresee their own self-control problems. Testing for these systematic errors is beyond the scope of this paper. The experimental literature has not yet developed a set of tools powerful enough to make satisfactory inferences from evidence gathered in situations where the agents make mistakes about their own preferences. It is worthy to note, however, that the actual pattern of time use of the individuals that selected option A did not look like what you could expect from a naive hyperbolic discounter. Most students nearly perfectly smoothed time use; some followed decreasing patterns, some increasing and some preferred to settled down for hump profiles. Trying to test empirically for the presence of exponential discounters, naive hyperbolic discounters and sophisticated hyperbolic discounters is an open challenge for future research.

6. Conclusion

Do we observe hyperbolic discounting? At this point, we believe the evidence is not as one-sided as sometimes claimed. It is a robust fact that people choose present goods more frequently than implied by a simple full-information model with exponential discounting. However it has been shown that as soon as we depart from this simple model, standard theory can account for the observed behavior at least as well as the hyperbolic discounting. Also, our alternative experiment that controls for uncertainty finds results that favor exponential discounting.

Another alternative is to judge the competing theories by their empirical implications. Here the burden of proof is on the side of hyperbolic discounting. It is true that the existence of some commitment devices can be interpreted as a *prima facie* proof in favor of hyperbolic discounting. The puzzle is however why, if agents face self-control problems, the market does not more of these self-commitment devices or why nothing like the asset pricing implications of hyperbolic discounting, such as the existence of Dutch Books, are observed.

This criticism can be answered in part, noticing that agents may be heterogeneous, with a fraction of them that discount hyperbolically and another fraction that discount exponentially. Since, presumably, these last ones are the individuals driving intertemporal pricing, it may be difficult to observe a strong aggregate effect of hyperbolic discounting even if it is relevant to account for micro data. The results from our experiment, where a fraction of the agents chose to commit, suggest that exploring a mixed model like the one outlined above is worthwhile.

Our conclusion is simple. So far, we have not seen enough evidence, direct or circumstantial, that hyperbolic discounting is a *basic* characteristic of *most* agents preferences. However we do not think that the issue is solved and we personally see hyperbolic discounting as an intriguing possibility. We need more realistic grounded models of intertemporal choice and behavioral economics has made several seminal steps in this direction. We eagerly wait for further research from both sides of the debate that will cast further light on the issue. In particular we conjecture that, in the close future, Cognitive Neuroscience may be able to provide much more powerful evidence about how individuals discount over time.

7. Appendix: Instructions for Individual Choice Experiment

1. General

You are about to participate in an experiment in the economics of individual choice. Various research foundations have provided the funding for this project. If you follow these instructions carefully, you will earn $30 just for playing games on the computer.

Please do not talk during the experiment. If you have any questions, raise your hand and an experimenter will assist you.

The experiment consists of your choosing between two options, A and B, and meeting all of the requirements of the option that you have chosen. These requirements are described in section 2 below.

Once you have completed all of the requirements of the option that you have chosen, you will be paid an additional $30 in cash. If you fail to complete all of the requirements of the option that you have chosen, you will not be paid any amount. Note that this payment does NOT depend on whether you chose B or A, but depends only on completing the requirements of the option that you have chosen. Also, the payment does NOT depend on what other subjects in this experiment choose. Just choose the option that you like the most.

2. The Options

You will have 180 minutes to play different games on the computers installed in the lab in 3-114 in the Carlson School of Management building from Monday to Wednesday in the week of 24th April to 26th April. Your choice concerns how you want to distribute these minutes.

Option A

If you choose option A), you will have 60 minutes on Monday 24th April, 60 minutes on Tuesday 25th April and 60 minutes on Wednesday 26th April. You can come in any time from 10 a.m. to 5 p.m. (from 24th April to 26th April) and then use your 60 minutes for the appropriate day in the lab.

You do have to attend on all three days. You should also sign your name on a control sheet, so we can verify that you have attended on all three days.

At the end of your last 60 minutes on Wednesday, if you have attended all three days as required, you will be paid $30 in cash.

Option B

If you choose option B), you can decide how you want to distribute a total of 180 minutes over the three days, Monday 24th April, Tuesday 25th April and Wednesday 26th April. You can come in any time from 10 a.m. to 5 p.m. (again, from 24th April to 26th April) to the lab.

You do have to attend on all three days. You should also sign your name on a control sheet, so we can verify that you have attended on all three days. So for example, you could choose to play 100 minutes on Monday, 0 on Tuesday and 80 on Wednesday, but on Tuesday you need to come to the lab, sign the sheet and then leave if you want to play for 0 minutes on that day.

At the end of your session on Wednesday, if you have attended all three days as required, you will be paid $30 in cash.

Your choice

After you have read the instructions, you will make your choice - between Option A and Option B - TODAY. Once you have made your choice TODAY, you CANNOT change your choice.

3. The Games

The lab in which you will participate in the experiment has a network with many computers. Each computer has three or more games installed on it. During your playing time,

regardless of whether you have chosen Option A or Option B, you are free to change from one game to the other, if you wish.

4. The Experimental Lab

The lab is located on the 3rd floor of the Carlson School of Management Building in room 3-114. The lab will be open for this experiment 10 a.m. to 5 p.m. during the period 24th to 26th April. During this time, you may choose to attend at any time according to your schedule. If you have any questions about the experiment at any time, you may contact either Professor Mukherji by telephone (624-9825) or e-mail (amukherji@csom.umn.edu) or Jesús Fernández-Villaverde by telephone (204-5492) or e-mail (jesusfv@econ.umn.edu).

5. Before we begin

If you have any question regarding the experiment, ask them NOW. To ensure that you understand the instructions, please answer the following questions. An experimenter will check your answers when you are finished.

a) My payment will NOT depend on the choice of option A) or B) but in following the requirements of the option that I have chosen.

True False

b) For both options A and B, I need to come to the lab three times.

True False

c) I am allowed to change options when I want.

True False

d) Every time I go to the lab, I need to sign my name on a control sheet.

True False

e) I can play any of the games in the computer without any limitations except time.

True False

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Figure 1: Share of Population Choosing Consumption Today

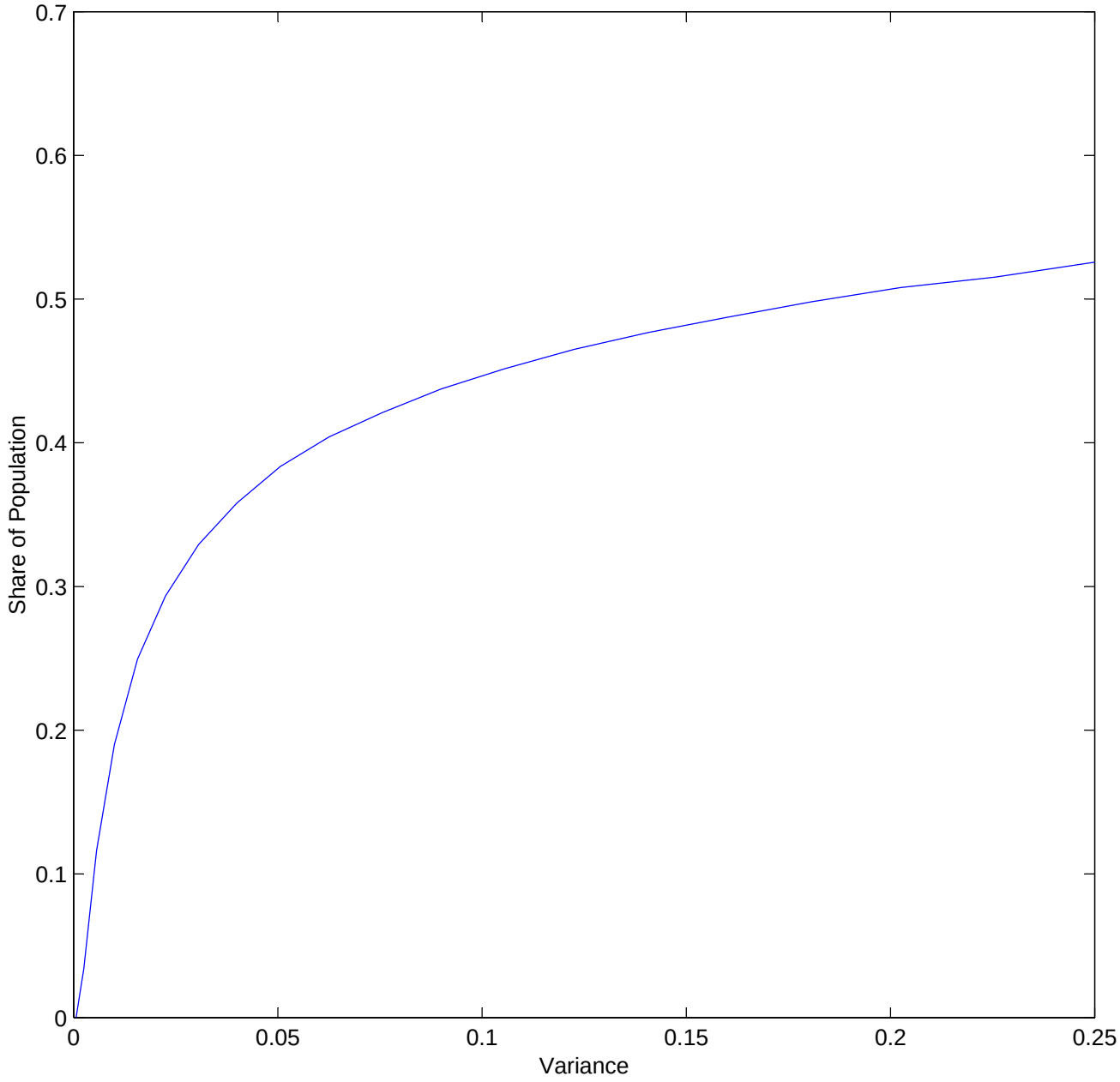
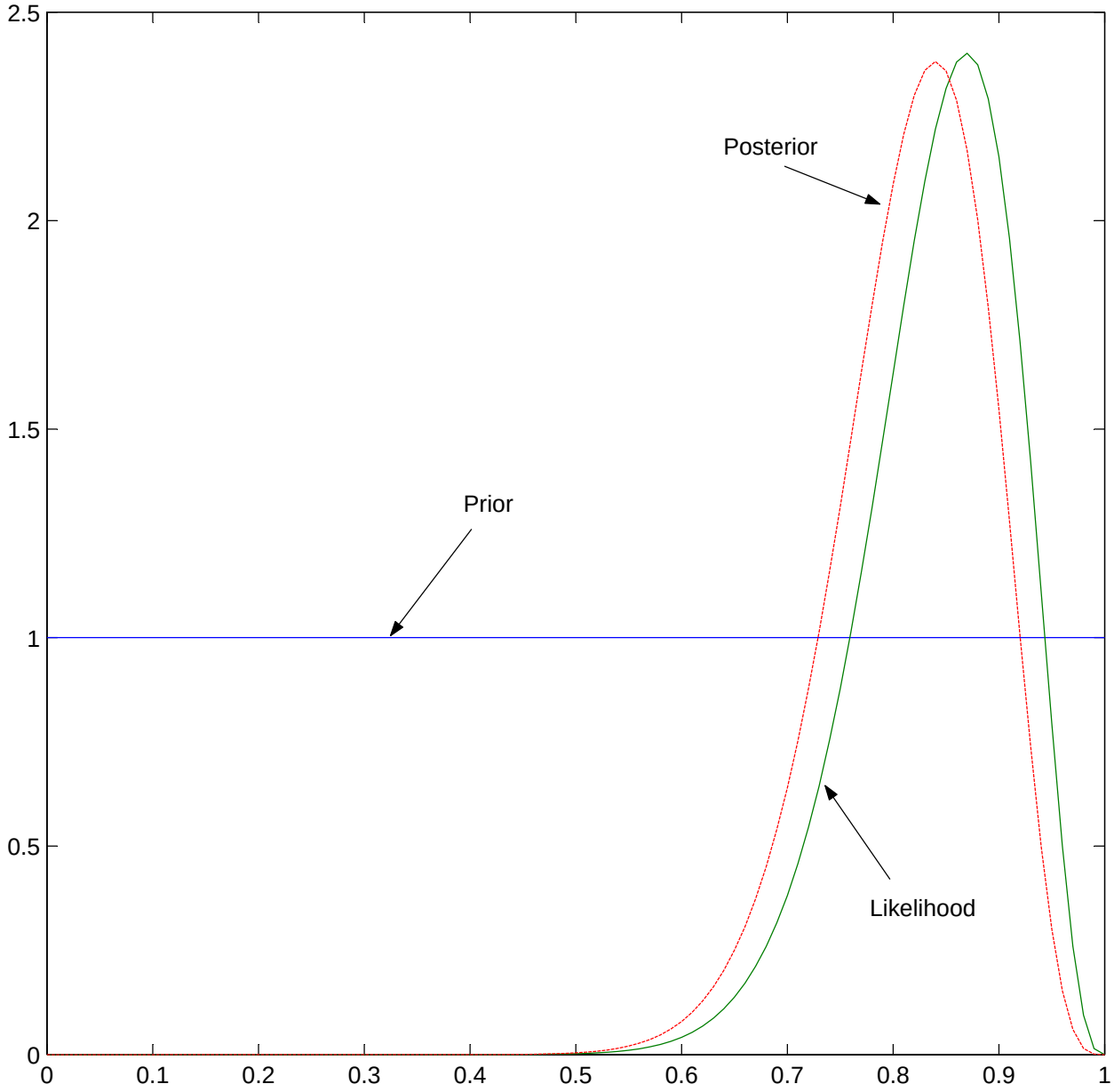
Figure 2: Prior, Posterior and Likelihood