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Boiling the frog optimally: an experiment on survivor curve shapes and internet revenue

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Boiling the frog optimally: an experiment on survivor curve shapes and internet revenue

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Abstract

When should a necessary inconvenience be introduced gradually, and when should it be imposed all at once? The question is crucial to web content providers, who in order to generate revenue must sooner or later introduce advertisements, subscription fees, or other inconveniences. Assuming that eventually people fully adapt to changes, the answer depends only on the shape of the "survivor curve" $S(x)$, which represents the fraction of a user population willing to tolerate inconveniences of size x (Aperjis and Huberman 2011).

We report a new laboratory experiment that, for the first time, estimates the shape of survivor curves in several different settings. We engage laboratory subjects in a series of six desirable activities, e.g., playing a video game, viewing a chosen video clip, or earning money by answering questions. For each activity we introduce a chosen level $x \in [x_{\min}, x_{\max}]$ of a particular inconvenience, and each subject chooses whether to tolerate the inconvenience or to switch to a bland activity for the remaining time.

Our key finding is that, in general, the survivor curve is log-convex. Theory suggests therefore that introducing inconveniences all at once will generally be more profitable for web content providers.

Keywords: Internet monetization; online advertising; pricing; reference points; adaptation; laboratory experiment
JEL classification: C91, D40, L11.

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1 Introduction

> Here is how *not* to boil a live frog: boil up a pan of water, pick up the frog and throw it in the pan. The art of frog-boiling is an ancient one
>
> How to boil a live frog
> (Goldstein 2000)

A goal of content providers is to turn attention to their websites into revenues that will at least offset their costs. Achieving this goal is not easy, even for providers with established audiences.

Providers may charge subscription fees, present advertisements or some mix (Baye and Morgan 2000, Prasad et al. 2003, Kumar and Sethi 2009). But all revenue strategies take a toll — while some users see the nuisance as a fair exchange for the value obtained, other users see the nuisance as intolerable and leave the website, and some potential users are deterred from joining. The issue is especially acute with increasingly intrusive "rich media" advertising formats (Godes et al. 2009).

In this paper we do not investigate which revenue strategy is best, nor how to choose the optimal nuisance level in steady state; presumably the best choices are very situation specific. Instead we ask a simpler question: should a content provider introduce the necessary nuisance in gradual steps or all at once? One view is that website visitors are like Goldstein's proverbial frogs, and that very few of them will leave if the inconvenience is introduced sufficiently gradually. Another view is that it is best to introduce inconvenience all at once.

An incorrect answer can cause lasting damage. A case in point is "TimeSelect" a subscription service started by the New York Times on May 2005 which allowed subscribers to read op-ed columnists and other features for a yearly subscription of $49.95. The service was discontinued on September 2007 when it became clear that the number of subscribers was insufficient. A second example is Digg's disastrous release on August 25, 2010 of its advertising-heavy v4. Netflix's share price crashed from $295 in July 2011 just prior to announcing an abrupt price hike on their old and new products, and hovered around $65 in November 2011. (After adjusting access and delivery options, Netflix recovered and their stock price reached new highs in 2014.) Of course, the issue of all at once versus gradual introduction is not confined to the internet; witness the swimmers' perennial debate of whether to jump into cold water or to wade in gradually.

After a brief literature review, we begin in Section 3 by recalling the model of Aperjis and Huberman (2011, 2012). It establishes that, under a set of auxiliary assumptions, the answer to the question hinges on the shape of the survivor curve $S(x)$, the fraction of a human population willing to tolerate an inconvenience of magnitude x. If the logarithm of $S(x)$ is convex, then the content provider maximizes value by introducing the necessary nuisance all at once. If the logarithm of $S(x)$ is concave, then the nuisance is best introduced gradually according to a schedule that balances the number of long-term users against more rapid revenue acquisition.

Are survivor curves typically log-concave, log-convex, or neither? To the best of our knowledge, previous research provides no clear evidence. Behavior in natural settings is difficult to interpret because visitors leave for many reasons unrelated to the chosen inconvenience increment x, while new visitors arrive that may have different reactions to x and to the content. Moreover, when a change x is introduced, visitors may form beliefs about further inconveniences that may be introduced later, and such beliefs could vary widely across visitors. Competitors' adjustments in inconvenience might also have a major impact.

Laboratory experiments are especially helpful to answer the shape question, because one can control for all these confounding factors, and can systematically vary the nuisance size x. In section 4 we describe a recent experiment designed to discover the shape of the survivor function over a variety of domains. The experiment confronts 112 human subjects with six different tasks interrupted by nuisances of magnitude $x \in [x_{\min}, x_{\max}]$. It generates 636 binary observations of decisions whether to stay with an enjoyable activity or to leave after the nuisance has been imposed.

Section 5 collects the results. Summary statistics and preliminary analysis show that the chosen ranges $[x_{\min}, x_{\max}]$ are reasonably well calibrated, that order effects are unimportant, and that behavior is reasonably consistent across tasks. The main finding concerns the shape parameters in Weibull distributions estimated for data from each of the six tasks. Estimation requires extension of established techniques to deal (for the first time that we know of) with doubly censored data. Surprisingly (at least to some of the coauthors), the overall estimate of the shape parameter is well inside the log-convex region.

The concluding discussion notes some caveats, suggests broader applications and implications, and points to future research.

2 Related Literature

We know of no studies estimating the shape of survivor curves for scalable nuisances. Own-price demand elasticity is a distantly related topic with a vast literature. Perhaps the most relevant article here is Popescu and Wu (2007), which argues theoretically that firms with risk averse customers maximize profits by gradually increasing or gradually decreasing price. In an adaptation model, Fibich et al. (2005) find that price elasticities increase over time, and that data suggest a faster adaptation for price decreases than for price increases.

A separate strand of literature on adaptation theory considers how users react over time to an introduced inconvenience. A number of papers consider adaptation in the context of repeat-purchase markets and characterize optimal dynamic pricing policies (Kopalle et al. 1996, Fibich et al. 2003, Popescu and Wu 2007, Nasiry and Popescu 2010). In these papers, a firm (usually a monopolist) is facing consumers whose purchase decisions are influenced by past prices through reference price effects. The demand in a given period is assumed to be a function of the current price and the reference price (but does not depend on the number of people that purchased the product in the previous period). In a laboratory experiment, Kahneman et al. (1993) suggest that duration plays a role in the recollection of aversive experiences, with reference points being formed at the peak and end of the negative experience.[1]

In fact, there is an active theoretical literature on reference points (Kahneman and Tversky 1979, Frederick and Loewenstein 1999, Kőszegi and Rabin 2006) which has inspired many recent laboratory experiments, including Gneezy (2005) and Baucells et al. (2011). Abeler et al. (2011) find empirical evidence supporting Kőszegi and Rabin (2006): payoff expectations seem to anchor reference points, as identified by subjects' effort choices. By contrast Heffetz and List (2011) find no support for the expectations reference point hypothesis. Closely related to this literature we find a number of experimental and empirical studies that focus on the formation of reference points (surveys are provided by Kalyanaram and Winer 1995, Mazumdar et al. 2005). In these studies, the inconvenience is the price of a product, and thus the reference point is a reference price. Even though the role of historic prices in forming price expectations

[1]The empirical adaptation literature is also related to studies such as Ariely (1998) that examine how remembered pain relates to the time path of pain intensity. It may be worth pointing out that our own concerns are quite different: we shall examine empirically how stay/remain decisions (not recollections) depend on one-shot intensities (not time paths) of nuisances (not pain) in a variety of modalities.

is supported in many of these studies, there has not been sufficient evidence to validate any specific model on how consumers update their reference prices.

Finally, there is a classic psychology literature on "just noticeable differences," which is associated with failures in the transitivity of preferences as in the self-torturer example of Quinn (1990), or in the Sorites paradox.[2] Finally, there is field data suggesting that firms generally prefer subdividing price increases but not price decreases (Chen et al. 2008).

3 Theory

We consider the setting of Aperjis and Huberman (2011). In discrete time $t = 1, 2, 3, ...$, each period the content provider has the option to adjust the total inconvenience level (e.g., advertisement level, subscription cost) X_t. Let $x_t \equiv X_t - X_{t-1}$ denote the adjustment in inconvenience at time t.

Assume that in period t, users have a reference point r_t and use the website with probability $S(X_t - r_t)$, where $S : \mathbb{R} \to [0, 1]$. That is, we assume that this probability only depends on the difference between the current inconvenience and the reference point. We assume that S is a decreasing function: the larger the difference between total inconvenience and the reference point, the smaller the probability of using the website.

Aperjis and Huberman (2011) rely on adaptation theory to describe reference point dynamics. That theory says that as time goes on people tend to adapt and become less aware of past changes. In the present context, an increase in inconvenience by an amount x initially decreases a user's utility. However, as time goes by the user's reference point gradually adapts and, as a result, his experienced utility gradually increases if no additional inconvenience is experienced.

Here we focus on the special case of "complete" adaptation within a single period. That is, we assume that $r_t = X_{t-1}$. In this case, the probability that a user continues using the website at time t is equal to $S(X_t - X_{t-1}) = S(x_t)$. Thus subsequent theoretical analysis assumes that the survivor curve S is the same in each period and depends only on the most recent change in inconvenience.

Other simplifying assumptions are straightforward. Once a user leaves, he never returns, so the fraction of users remaining on the site at time t is $\rho_t = \prod_{j=1}^{t} S(x_j)$. The provider wishes to maximize the present value of his profit stream, $\sum_{t=0}^{\infty} \delta^t \rho_t \pi(X_t)$, where δ is the provider's discount factor and the current per-unit profit level $\pi(X_t)$ is an increasing function of the current inconvenience level.

The main conclusion of Aperjis and Huberman (2011) is that, under current assumptions, the provider's optimal schedule of inconvenience changes $(x_1, x_2, ...)$ depends entirely on the shape of the survivor curve. There are two important cases.

Log-concave survivor curve. A function is log-concave if its logarithm is concave. All concave and linear functions are log-concave, but there also exist convex functions that are log-concave. Examples include $S(x) = e^{-x^k}$ with $k > 1$ and $S(x) = (1 - x)^k \cdot 1_{\{x \in [0,1]\}}$ with $k > 1$, where $1_{\{\cdot\}}$ is the indicator function. An important property of a log-concave survivor curve is that

$$S(x + y)S(0) \leq S(x)S(y)$$

for any $x, y \geq 0$. Here $S(x)S(y)$ represents the probability that a current user will continue to be a user if inconvenience increased by x last period and then by y this period, while

[2] In Greek, soros means heap. The paradox is attributed to Eubulides of Miletus, a disciple of the Megarian school of philosophy who presented the following paradox: "no one grain of wheat can be identified as making the difference between being a heap and not being a heap. Given then that one grain of wheat does not make a heap, it would seem to follow that two do not, thus three do not, and so on. In the end it would appear that no amount of wheat can make a heap." (Hyde 2011)

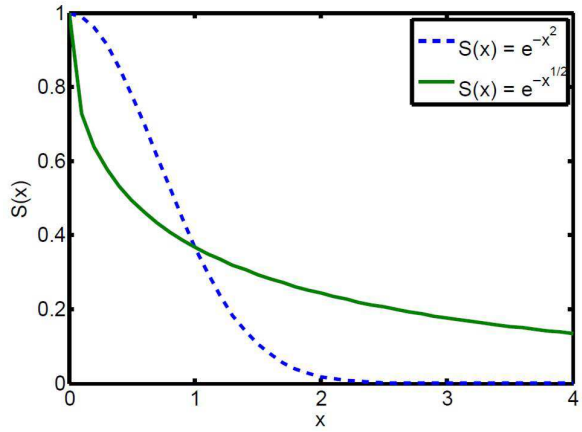

Figure 1: A comparison between a log-convex and a log-concave function.

$S(x+y)S(0)$ represents the corresponding probability when the entire inconvenience change $x+y$ was introduced in the current period. Iterating the inequality, it is intuitively clear that when S is log-concave, more users will remain if an increase in inconvenience is introduced gradually than if it is introduced all at once.

Aperjis and Huberman (2011) confirm the intuition, and show that in the log-concave case it will be optimal for the provider to increase inconvenience gradually in order to give people time to adapt to changes. That paper then derives a specific schedule of changes that optimizes the tradeoff between maximizing the number of users in the long term and achieving a higher revenue per user sooner.

Log-convex survivor curve. A function is log-convex if its logarithm is convex. For instance, this is the case if $S(x) = 1/(1+x)^k$ with $k > 0$ or $S(x) = e^{-x^k}$ with $k \in (0,1)$. If S is log-convex, then $S(x+y)S(0) \geq S(x)S(y)$ for any $x, y \geq 0$, and therefore a user is more likely to stay if an increase in inconvenience is introduced at once than if it introduced gradually. When the survivor curve is log-convex, it is optimal for the provider to increase inconvenience once; this is shown by Aperjis and Huberman (2011) in a more general setting than the one we consider here. Note that this is *not* a result of selection, because the function S is assumed to not change over time.

To get some intuition for the distinction between log-concave and log-convex survivor curves, consider Figure 1 which shows the log-concave function e^{-x^2} and the log-convex function $e^{-x^{1/2}}$. Note that for small deviations x from the reference point, the dashed line is above the solid line, indicating that a user is more likely to use the website when his behavior is described by the log-concave function. On the other hand, for large deviations ($x > 1$ in the Figure) the comparison is reversed, suggesting that if the survivor function is log-convex, it is better to make one large change.

Given that the optimal way to introduce inconvenience is so different for log-concave and log-convex survivor curves, it is important to understand whether one of the two shapes prevails. This motivates us to measure the survivor curves in the laboratory for a number of different activities and types of inconvenience.

4 Methods

The laboratory experiment presented subjects with tasks of the following sort. First, they engaged in a pleasurable activity, such as putting on earphones and watching an 8 minute video clip — their choice of an interview of John Stewart at The O'Reilly Factor, or a selection of the 10 most popular ads shown to viewers of the 2010 Super Bowl. (Pilot experiments included

a longer list of videos, but these two were the most popular.) Then, after 100 seconds, an annoying computer-generated voice at $x \in [30, 80]$ decibels began reading the decimal expansion of $\pi = 3.14159...$. Subjects knew that the only way to escape the auditory nuisance was to click a button that immediately switched them to a bland activity, in this case watching a video of gentle waves breaking at La Jolla beach, for the remaining 6 minutes or so. Of course, a higher fraction of subjects switched when $x = 80$ decibels than when $x = 30$, and intermediate fractions switched at intermediate values x of the nuisance.

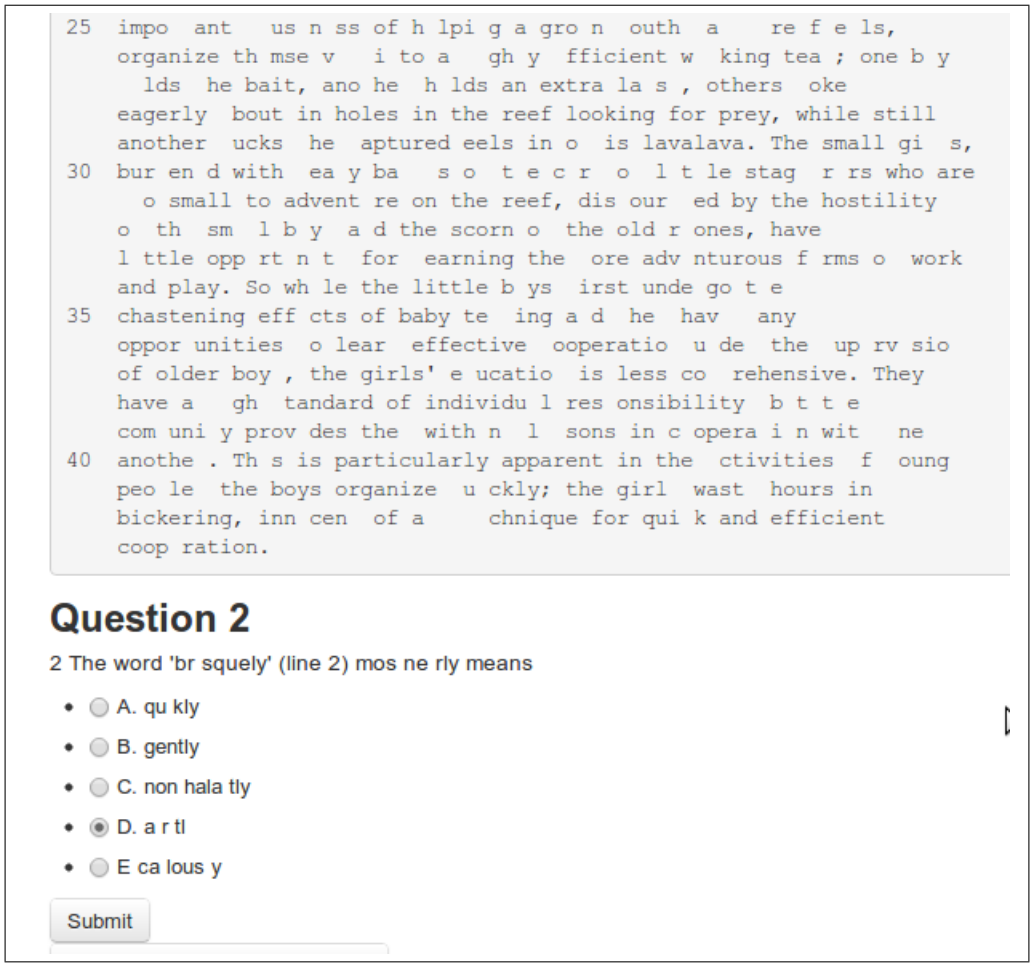

Figure 2: SAT task with nuisance $x = 0.15$

We also presented subjects with visual nuisances, like flashing pop-up ads that interrupted a video clip for 15 seconds every x seconds, with x ranging from $x = 5$ to $x = 30$. Figure 2 shows a text-based nuisance for the task of answering SAT questions, with a \$0.40/\$0.10 payment for each correct/incorrect answer. The nuisance is the random omission of each letter with probability $x \in [0.06, 0.21]$; in Figure 2, $x = 0.15$. Subjects could escape the nuisance entirely by clicking a button, but then would be paid for the remainder of the 8 minute period at the much lower rate of \$0.10/\$0.02.

We presented each subject with six distinct tasks that shared the common structure depicted in Figure 3. The subject starts with an engaging activity (A activity), which after a certain amount of seconds is interrupted by a scalable nuisance of size x that remains attached to the A activity thereafter. She can escape the nuisance at any time by clicking a button to switch to a "bland" activity (B activity) where she will remain for the rest of the 6-8 minute period. Her choice of whether or not to switch is a data point that helps us estimate the shape of $S(x)$.

Table 4 summarizes the six combinations of A activity, scalable nuisance, and B activity

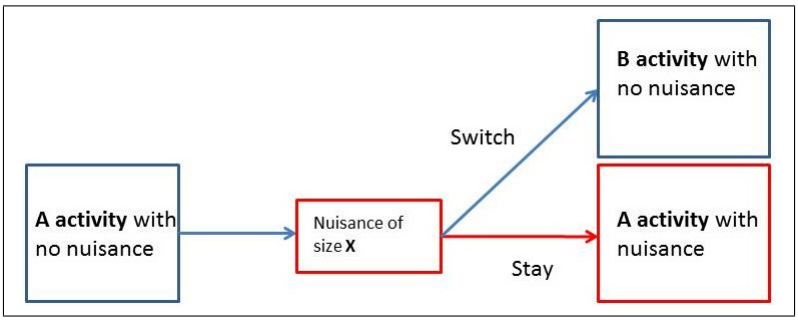

Figure 3: Task structure. The inconvenience is introduced to activity A after 100 seconds and remains for the rest of the 6-8 minute period.

Task	Activity A	Activity B	Inconvenience:	Range of x
Movie/Pi	Watch Movie	Watch Waves	π digits	[30, 80] decibels
Movie/Pop	Watch Movie	Watch Waves	15 sec Pop-up	every [5, 30] sec
Slug	Slug ($$$$)	Slug ($)	Jitter	[0.10, 0.25] rate
Read	Read Article	Count Bits	Drop Letters	[0.15, 0.30] rate
SAT	SAT Questions ($$$$)	SAT Questions ($)	Drop Letters	[0.06, 0.21] rate
Pay	Watch Movie	Watch Waves	Pay to Stay	[1, 23] cent fee

Table 1: Task specification.

presented to each subject. Of the entries not yet mentioned, Slug is a simple video game similar to Snake (see Appendix B for a detailed description of the activity), and the jitter nuisance involves a random turn (left or right) each pixel with probability $x \in [.10, .25]$. The Pay to Stay nuisance is a one time fee of x cents deducted from a 500 cent endowment, which can be avoided only by switching to the B activity. The B activity Count Bits is illustrated in Figure 4 below. Paid activities are indicated by ($$$$), and B activities paid at 1/4 the rate are indicated by ($).

The nuisance ranges $[x_{\min}, x_{\max}]$ were chosen to avoid inefficient sampling when $S(x)$ is very close to 0 or 1. Based on a few pilot sessions, we aimed to have $S(x_{\min})$ in the vicinity of 0.8 and $S(x_{\max})$ in the vicinity of 0.20. Nuisance levels were chosen to span the range by six evenly spaced levels, as detailed in Appendix A.

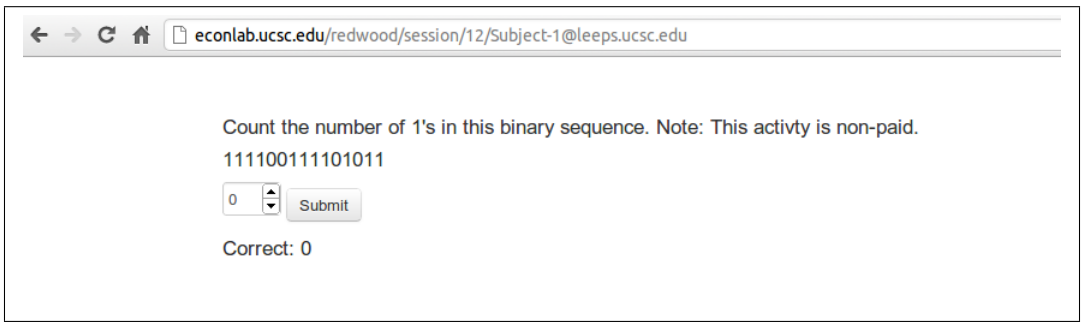

Figure 4: Counting Bits. The subject is asked to count the number of ones in a random binary string of 15 digits. If incorrect, she is asked to try again. If correct, she goes on to a new string. The task repeats until the end of the 6 minute period.

4.1 Procedure

We recruited 112 human subjects, most of them undergraduates, majoring in Economics, Biology or Engineering. Each subject participated in only one of the 16 sessions we ran. Sessions lasted 70 to 90 minutes, including the time used to read instructions and to pay subjects.

Upon arrival, each subject was assigned to an isolated computer terminal, and general instructions for the experiment were read; a copy is attached in Appendix C. Next, subjects practiced all B activities, in order to ensure that they knew exactly what they would do if they decided to switch to a bland activity. Subjects were then given specific instructions for the first of the six tasks, after completion they received instructions for the second task, completed it and were given instructions for the third task, etc. The order of the six tasks was varied in a balanced manner across sessions. In each session we randomly assigned each subject's nuisance level x, but limited the choice to one of the two nuisance bins that we created; either $x = 1, 3, 5$ or $x = 2, 4, 6$ in each session. These bins allowed us to have in each session a sizeable number of observations with the same treatment level in each activity.

Before each round it was announced whether A and B would be paid activities. If they were, then a detailed description of the payment system was given. If they weren't paid, then we emphasized it in the instructions. Subjects would know how much money they had made at the end of each paid round, and once the experiment was over, they were paid individually. Payoffs ranged from \$27 (some subjects proved very proficient at Slug) to \$12 (some were not that apt), including the \$5 show-up fee. On average subjects made around \$16.

5 Results

The experiment yielded 636 data points ($Y_{i,j}$), observations of whether or not subject i decided to switch after experiencing inconvenience level x in task j. Due to implementation glitches, we lost one Slug data point and the SAT data in two sessions (35 data points); hence the slight shortfall from the intended $6 \times 112 = 672$ observations. Figure 5 summarizes the data graphically.

As a first step in the data analysis, we run a Probit regression of the binary outcome ($Y_{i,j}$) on dummies for inconvenience levels 2-6, task numbers 2-6 as in Table 2, and the task sequence or session[3].

As we can see in Table 2 all levels of inconvenience have a highly significant effect, as one would hope. So do most tasks, except Movie/Pop, which is not significantly different than the baseline task, Movie/Pi. Appendix A reports additional robustness checks, and confirms that there were no important session or sequence effects.

Finally, we use a Fisher Exact test to compare the proportion of subjects switching for each value of x across activities. The results show that for any value of x the difference in proportion is not statistically significant, pointing towards a similar underlying distribution of subject tolerance for nuisance levels across activities. This conclusion will be tested more sharply in our survivor curve estimates below.

5.1 Estimation Strategy

The main objective of our experiment is to detect log-concavity or log-convexity of $S(x)$ separately in each of our six tasks. To do this we will consider each observation (switch or not) for each subject i as an independent observation for each separate curve j.

[3] The errors are clustered at the subject level.

	(1) Switch	(2) Switch	(3) Switch	(4) Switch
2.treatment	0.299*		0.359*	0.735***
	(0.180)		(0.190)	(0.280)
3.treatment	0.578***		0.633***	0.649***
	(0.171)		(0.187)	(0.177)
4.treatment	0.524***		0.642***	0.968***
	(0.165)		(0.175)	(0.257)
5.treatment	0.746***		0.845***	0.913***
	(0.164)		(0.178)	(0.199)
6.treatment	0.737***		0.859***	1.265***
	(0.179)		(0.196)	(0.281)
2.activity		0.0511	0.0591	0.180
		(0.174)	(0.176)	(0.194)
3.activity		0.551***	0.583***	0.708***
		(0.174)	(0.176)	(0.185)
4.activity		1.029***	1.072***	1.322***
		(0.172)	(0.174)	(0.243)
5.activity		1.144***	1.238***	1.339***
		(0.199)	(0.191)	(0.238)
6.activity		0.428**	0.444**	0.554***
		(0.170)	(0.177)	(0.185)
cons	-0.524***	-0.540***	-1.133***	-1.282***
	(0.125)	(0.125)	(0.186)	(0.221)
N	636	636	636	636
Order Dummies	No	No	No	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Switching Probit Model.

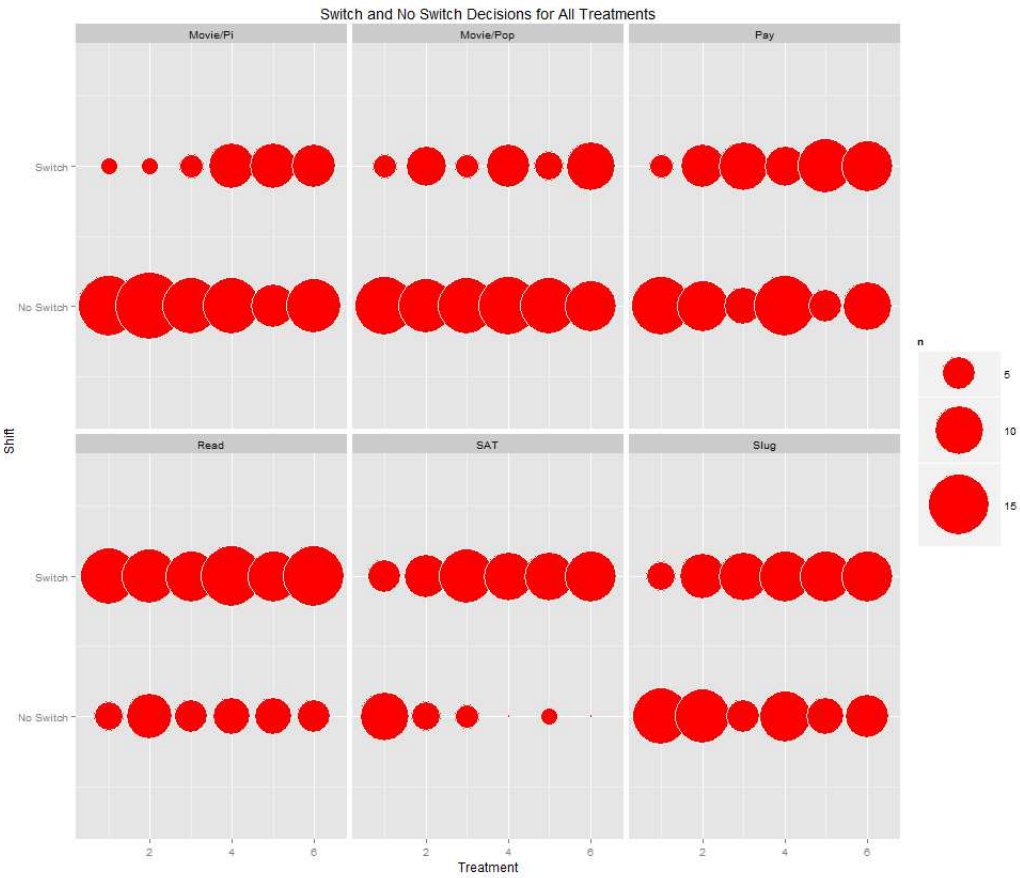

Figure 5: Overview of raw data. Ovals are proportional in each task to the number of observations of outcome $Y = 1$ (Switch) and of outcome $Y = 0$ (No Switch, or Stay) for the given inconvenience level.

The main complication with our data comes from censoring. If $Y_{ij} = 1$, i.e., if subject j switches to the bland activity B when facing nuisance level x_i, then we infer that her switching threshold X is somewhere in the interval $(0, x_i)$, and thus observation is left censored (LC). Therefore the likelihood of the observation is given not by the density of the distribution of thresholds at x_i but rather by the cumulative distribution function F evaluated at that point:

$$F(x_i) \equiv P(X \leq x_i)$$

On the other hand, if $Y_{ij} = 0$, i.e., if subject j stays in activity A, then we infer that his threshold is in the interval (x_i, ∞), and the observation is right censored (RC). The likelihood of such an observation is

$$1 - F(x_i) = P(X > x_i),$$

where $S(x_i) \equiv 1 - F(x_i)$ is the probability that the subject "survives" the introduction of the inconvenience.

This likelihood function applies to any parametric family of survivor curves. We use the standard two-parameter Weibull family. Recall that the Weibull distribution has density

$$f(x; \gamma, \kappa) = \begin{cases} \frac{\kappa}{\gamma}(\frac{x}{\gamma})^{\kappa-1} e^{-(\frac{x}{\gamma})^{\kappa}} & if\, x \geq 0 \\ 0 & if\, x < 0, \end{cases}$$

where $\kappa > 0$ is the shape parameter and $\gamma > 0$ is a scale parameter for the distribution. The

corresponding cdf is $F(x;\kappa,\gamma) = 1 - e^{-\left(\frac{x}{\gamma}\right)^{\kappa}}$, and thus the survivor function is $S(x;\kappa,\gamma) = e^{-\left(\frac{x}{\gamma}\right)^{\kappa}}$.

Besides being standard, the Weibull family has the extremely convenient property that the shape parameter κ determines whether the survival function $S(x)$ is log-convex or log-concave (Bagnoli and Bergstrom 2005):

- $S(x)$ is log-convex (and the hazard rate is strictly decreasing) if $0 < \kappa < 1$, and
- $S(x)$ is log-concave (and the hazard rate is increasing) if $\kappa \geq 1$.

Econometric packages usually include the Weibull distribution, and sometimes can deal with singly censored data, but we must build our own likelihood function to deal with doubly censored data. It follows from the preceding discussion that the likelihood function for data $Y = (Y_{ij})$ is:

$$\begin{aligned} L(\gamma,\kappa|Y) &= \prod_{Y_{ij}\in LC} P(X < x_i|\gamma,\kappa) \prod_{Y_{ij}\in RC} P(X > x_i|\gamma,\kappa) \\ &= \prod_{Y_{ij}\in LC} \left(1 - e^{-\left(\frac{x_i}{\gamma}\right)^{\kappa}}\right) \prod_{Y_{ij}\in RC} e^{-\left(\frac{x_i}{\gamma}\right)^{\kappa}}. \end{aligned} \tag{1}$$

We maximize Function (1) over the parameter space using standard non-linear minimization techniques (a Newton-type algorithm) in the statistical package R to obtain point estimates of the shape parameter κ. The results are reported in Table 3 along with a 90% confidence interval obtained through the bootstrapping procedures appropriate for finite samples.

Task	Shape Parameter	90% Confidence Interval
Movie/π	1.17	[0.59, 1.99]
Movie/Pop	0.43	[0.11, 0.89]
Slug	0.60	[0.23, 1.09]
Read	-	-
SAT	0.92	[0.48, 1.48]
Pay	0.62	[0.24, 1.10]
All Six Tasks	**0.49**	**[0.32, 0.66]**
Five Estimable Tasks	**0.64**	**[0.49, 0.81]**

Table 3: Weibull estimation results. Estimates in the next to last line pool all data, and those in the last line pool data for all tasks except Read.

Several things stand out in Table 3. First, four of the six point estimates are for a shape parameter below 1. The two exceptions include Movie/π, which has an estimate close to 1, but with a confidence interval that includes a considerable interval below 1. The other exception is the task Read, where MLE does not converge. Looking back at Figure 5, one gets the impression that there is insufficient variation across the chosen range $[0.15, 0.30]$ of the nuisance (letter drop probability). Perhaps a contributing factor is that some of the subjects apparently enjoyed the B activity, bit counting, more than the A activity.

Looking at individual activities, then, in no case do we have clear log-concavity ($\kappa > 1$). Three of the tasks (Movie/Pop, Slug and Pay) have confidence intervals mainly or entirely in the log-convex region ($\kappa < 1$), and two (SAT and Movie/π) have confidence intervals that straddle $\kappa = 1$. The remaining task (Read) permits no estimate of κ.

The pooled data, whether or not we include the problematic Read data, yield a shape parameter clearly below 1. Indeed, the bootstrap histograms shown in Figure 6 have negligible probability mass for $\kappa > 1$.. Overall, then, the survivor curve of subjects is log-convex.

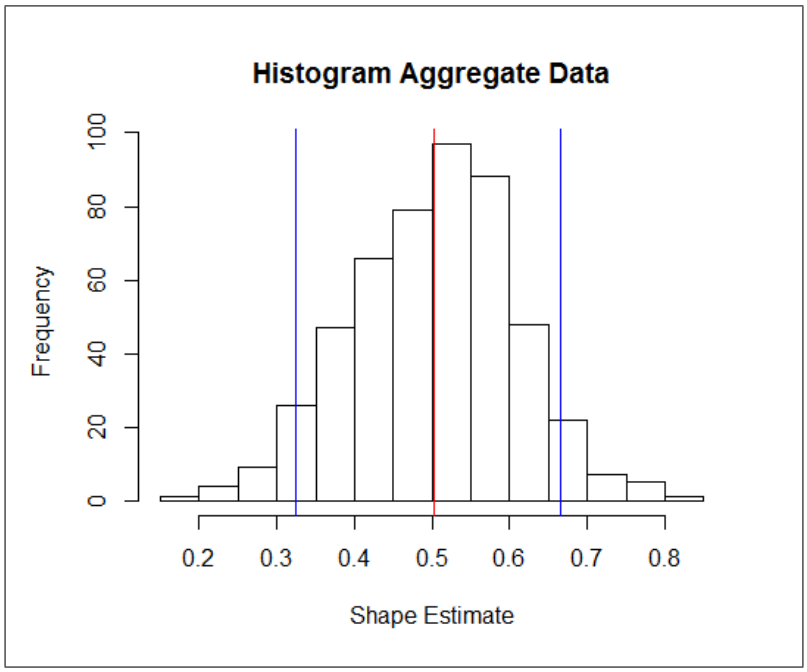

Figure 6: Histogram of bootstrap estimations of the shape parameter κ for the aggregate data across all tasks. The average estimate is shown as a red vertical line, and the 90% confidence interval is bounded by the two blue vertical lines.

6 Discussion

The lab results for the pooled data are unambiguous: the Weibull shape parameter estimate is well inside the log-convex region $\kappa < 1$. Looking at the results for individual tasks, the estimates are never inconsistent with a log-convex shape, but in half the cases they are ambiguous. We believe that the ambiguities are not intrinsic, but result from the limited data. Overall, then, our study — the first to estimate the shape of survivor curves in response to avoidable nuisances — concludes that log-convexity is typical.

A direct implication of a Weibull shape parameter $\kappa < 1$ is that the hazard rate (in other contexts sometimes called the failure rate) is decreasing.[4] This means that, proportionately speaking, we lose more participants at low intensity; the few who remain at high intensity are less apt to switch when we ratchet up intensity a bit more.

The implication is straightforward within the theoretical framework of Aperjis and Huberman (2011): web content providers should introduce their necessary nuisances all at once. In other words; it seems like the best way to boil a frog is by dropping it a pan of boiling water[5].

As with any empirical results, several caveats are in order. Our results are based on the decisions of more than 100 human subjects recruited from a subject pool consisting mostly of undergraduate students in a US university. It is entirely possible that other populations would be more or less tolerant of nuisances than ours, and thus have survivor curves with different scale or location. However, it seems to us rather implausible that they would yield survivor curves with much different *shape* than ours, but of course that can only be confirmed through further research.

[4] To see this, recall that the hazard rate $h(x) = f(x)/S(x)$ is the density for switching at nuisance level x conditional on not switching at a lower level, and for the Weibull distribution this function is proportional to $x^{\kappa-1}$. Thus $h(x)$ is an increasing function if $\kappa > 1$ and is decreasing if $\kappa < 1$.

[5] Anecdotally, our result is in line with those of real frog boiling attempts, as reported in online interviews by Dr. Victor Hutchinson Emeritus Professor of Biology at the University of Oklahoma http://srel.uga.edu/outreach/ecoviews/ecoview071223.htm

A second caveat is that we have worked within the framework of a simple model, which neglected potentially important aspects of reality. For example, it ignored the arrival of new users. A slight extension of the model could easily incorporate them if their survivor curves resembled those of the original users. Although new users might differ from the originals in various ways, again there is no reason to suppose that their survivor curves have radically different shape.

Perhaps the more important caveat, and the most intriguing, is that the adaptation process may differ from that envisaged in the theoretical model. As noted in the literature survey, there is considerable recent empirical research on such matters, much of it inspired by Prospect Theory and in particular by Kőszegi and Rabin (2006). So far the work seems inconclusive, but when a consensus emerges on reference point dynamics, it should be incorporated into a richer model of dynamic decision making.

7 Appendix A: Details

In Table 4 we present the different nuisance levels for each activity, and report the number of observations at each level.

Inconvenience	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Pi volume	30[11]	40[20]	50[12]	60[22]	70[13]	80[20]
Pop-up	30[11]	25[19]	20[12]	15[22]	10[13]	5[21]
Jitter	.10[11]	.13[21]	.16[12]	.19[22]	.22[13]	.25[19]
Reading	.15[11]	.18[21]	.21[12]	.24[21]	.27[13]	.30[20]
SAT	.6[9]	.9[8]	.12[11]	.15[11]	.18[12]	.21[12]
Movie Pay	1[11]	5[19]	9[12]	13[22]	17[13]	23[21]

Table 4: Nuisance Values [and Numbers of Observations].

In Table 5 we present the robustness checks for the probit model of Table 2, and present the results for ordering ($i.order$), and a series of dummies $pibigpop_{i,j}$, $popbigpi_{i,j}$, $readbigsat_{i,j}$, $satbigread_{i,j}$ that test the effects of having similar activities with different levels of nuisance. For example, $pibigpop_{i,j}$ ($popbigpi_{i,j}$) is a dummy for the case when the nuisance for Movie/Pi (Movie/Pop) is bigger than that for Movie/Pop (Movie/Pi); similarly $readbigsat_{i,j}$ ($satbigread_{i,j}$) is a dummy for the case where Reading (SAT) has a bigger nuisance level than SAT (Reading).

The results show that ordering has no statistical effect on the decisions of subjects, while different levels of inconvenience for similar activities seem to have an effect when Movie/Pi has a bigger nuisance than Movie/Pop (note that we only have 8 cases of this). Finally, for the 16 session dummies only one is significantly different (at the 5%) from our baseline.

We conclude thus that our results are robust, and even if we have a few dummies with significant effects, these are probably due to small sample bias.

	(4) Switch
[1em] 2.order	-0.315
	(0.223)
[1em] 3.order	-0.552
	(0.382)
[1em] 4.order	-0.516
	(0.334)
[1em] 5.order	-0.0737
	(0.287)
[1em] 6.order	-0.248
	(0.356)
[1em] 7.order	0.443
	(0.408)
[1em] 1.readbigsat	-0.249
	(0.261)
[1em] 1.satbigread	0.0678
	(0.515)
[1em] 1.popbigpi	-0.302
	(0.408)
[1em] 1.pibigpop	1.155**
	(0.536)
[1em] cons	-1.282***
	(0.221)
N	636
Session Dummies	Yes

Table 5: Switching Probit Model, Continued.

8 Appendix B: Description of activities

In this appendix we list all the activities that were not described in detail in the methods section.

Movie/Pop: Subjects were presented with a menu of two video clips (an interview of Zack Galifianakis by Letterman, and a clip on how to do crossover moves in basketball). After 100 seconds of visualization, a 15 second long pop-up would appear on the screen. This pop-up would partially cover the video clip, and have flashing colors; moreover, while the pop-up was on the screen, the movie clip would continue playing in the background but with no sound. The unit of the nuisance $x \in [5, 30]$ is the number of seconds between consecutive pop-ups, e.g., if a subject was assigned a nuisance level of $x = 5$, then she would have a 15 second pop-up every 5 seconds. If the subject decided that the nuisance was too big, then she could switch to the bland activity which, as in all movie activities, was a video of gentle waves breaking at La Jolla beach. Once a subject switched to the bland activity she would remain there until the end of the round. Rounds lasted 8 minutes.

Note on wave watching: The bland activity for all movie activities is "watching waves." We decided to use this video because as it has no plot, that is, its "replay value" is very high, allowing us to reuse it with almost no loss in its (relative) attractiveness.

Slug: Slug is a version of the classic video game Snake. Snake was a popular arcade game in the 1970's but gained world-wide acceptance in 1998 as it became the standard pre-loaded game in Nokia phones. The game has been used as "Easter egg" by both Youtube and Gmail. In this game the objective is to get "food," which corresponds to colored pixels that appear at random points of the enclosed "playing space." Each time the player gets to food she earns points, but the slug increases in size, making it harder to maneuver. To get to the food subjects control the slug with the keyboard arrows. If the slug bumps into the walls of the enclosed playing space, or if it hits itself, the player loses. Losing has no cost in points, the subject just need to restart the game by pressing the refresh button (F5 on the keyboard), and the game starts over with the same amount of accumulated points. As mentioned, points are awarded by getting to food; 10 points for regular food and 40 points for bonus food. The difference between these two types of food is that bonus food only stays on screen during 10 seconds, while normal food is there until eaten. Food is color coded, with bonus food being yellow, and regular food blue. Each point was worth \$0.01. The jitter nuisance would start 50 seconds into the round, and involves a random turn (left or right) each pixel with probability $x \in [.10, .25]$. The bland activity towards which subjects could switch was the same exact game without the jittering nuisance, but paying only one fourth of the amounts in the original activity (i.e., 10 points per bonus food, and 5 points for each piece of regular food "eaten"). Each round lasted 7 minutes.

Read: Subjects are given a menu with a series of articles from the New York Times (an article on the Proposition B for LA county, an article on veterans of the Iraq war coming back to the US, and an article on fee increase at the UC system). The nuisance $x \in [.15, .30]$ is the (independent) probability for each letter of being dropped. The first 15% of the text would be nuisance free. On the other hand, the text was presented broken into paragraphs. To ensure that subjects actually read the text, they could only move to the next paragraph by clicking a "next" button that would appear 10 seconds after the start of every new paragraph. The bland activity was counting bits, which presented subjects with a binary string of 15 digits, and asked them to count how many 1's were in the string. If the answer was correct, then a new string was generated. If the answer was wrong the subject would be given a new opportunity until he answered correctly. This would last until the end of the round, which was 6 minutes long.

SAT: Subjects could pick between two different texts taken from an SAT practice webpage. The text would be presented to subjects along with only one of the 8 multiple choice

questions they had in this round. All answers were final, and once a choice was made the next question would appear, with no way of going back. This was a paid activity and each correct answer would pay \$0.40, while each incorrect answer would penalize \$0.10. The nuisance for this activity was letter dropping, and worked exactly as in the Read activity. In this case each letter was dropped with probability $x \in [0.06, 0.21]$. The bland activity was the same task with all the letters, but paying one fourth (i.e., \$0.10 for each correct answer and -\$0.02 per incorrect answer). If a subject decided to switch, she would not start over all the questions, but would start the bland activity at the same question where she switched to activity B.

9 Appendix C: Instructions

Upon entering the lab subjects were read an initial set of instructions that described the structure of the experiment but did not give any details on the activities or inconveniences they would encounter; subjects were told that detailed instructions would be given before each round. These instructions appeared on separate pages for each separate task. However, to save space below, we omit the page breaks and put the detailed task instructions together in a single document.

9.1 General instructions

Welcome! This is an economics experiment. You will be a player in many periods of an interactive decision-making game. If you pay close attention to these instructions, you can earn a significant sum of money. It will be paid to you in cash at the end of the last period.

It is important that you remain silent and do not look at other people's work. If you have any questions, or need assistance of any kind, please raise your hand and we will come to you. We expect and appreciate your cooperation today.

The Experiment:

This experiment will have six different rounds. In each round you will begin with an enjoyable activity that we refer to as Activity A. At any time during the round you can switch to another activity, Activity B. The experimenter will announce the A and B activities for that round before it starts.

At the same time, the experimenter will also announce an "annoyance" that will accompany Activity A at some point during that round. If, after experiencing the annoyance, you think you would prefer Activity B, then simply click the button on your screen. It will immediately switch you to B, where you will remain for the rest of the round. You will never be interrupted by any annoyance in Activity B. Key points:

- You will start each round participating in an A activity.
- A activities will be interrupted by specific annoyances (announced before the round).
- At any point during the round you can switch from activity A to activity B (announced before the round)
- You can switch from A to B, but never from B to A.
- B activities do not have any interruptions.

Also note:

- Some rounds include a paid Activity and some do not.
- You automatically get to experience an A activity each round. To make sure that you are familiar with all with B activities, you will practice with all of them before the experiment starts.
- For some of the activities the audio output is needed. Please check if you have headphones attached to your computer. If you have your own, feel free to use them. You will be able to adjust the volume through the "speaker icon" on the upper right corner of your screen.
- Do not start Activity A until the experimenter announces that it is time to do so.

9.2 Specific activity instructions

Round Movie/Pi (8 minutes):

Activity A: Watching a video. You will choose it from a menu that will appear on screen.
Annoyance: While watching the video, at some point you will start to hear a computerized voice reading the first few thousand digits of the decimal expansion of $\pi = 3.14159\ldots$ This will continue at the same volume until the end of the round, or until you switch to activity B.
Activity B: Watching a video of waves breaking at La Jolla beach. This is not a paid round.

Round Movie/pop (8 minutes):

Activity A: Watching a video. You will choose it from a menu that will appear on screen.
Annoyance: While watching the video, at some point a pop-up will appear on your screen and mute the audio. These pop-ups are 15 second long, and will appear at regular intervals on your screen. The time remaining is shown on the pop-up.
Activity B: Watching a video of waves breaking at La Jolla beach. This is not a paid round.

Round Slug (7 minutes):

Activity A: Playing a game called "Slug", very similar to the popular game "Snake." Use your arrow keys to control a hungry slug. The slug gets longer as it eats food, and you earn points:

- Regular food (Blue Pixel): will stay on screen until you eat it, each piece that you eat which gives you 20 points.
- Bonus food (Yellow Pixel): gives you 40 points, will appear randomly and only lasts for 10 seconds on screen, if you don't eat it during this time it disappears.

Your slug will "die" whenever it collides either with an edge of its rectangle or with its own body. But the points you earned are stored and accumulated, and you can begin again with a new slug. Just hit the refresh page key (F5) and the game will restart with a new short slug.
Annoyance: At some point the slug starts to "jitter." That is, with some probability, it will change direction randomly each time it reaches a new pixel. The jitter rate (probability) will remain the same for Activity A the rest of the round.
Activity B: Playing the same game, "Slug," but with two differences:

- The slug will not jitter
- You will earn points at 1/4 the previous rate: 5 points per blue pixel, 10 per yellow.

Round Read (6 minutes):

Activity A: Reading newspaper articles. You will choose one from a menu, and the text will appear on your screen. The text will be broken up into different pages. After 10 seconds "next page" button will appear. Just click the button to move to the next page. On the last page, please press the button to indicate when you are done reading the article.

Annoyance: In this activity the annoyance will be that some letters of the text will be missing. With a certain probability letters will be dropped from the article. This will apply to all the text, except the very beginning. As usual, press the button if you would rather go to the B activity than continue trying to read the article with missing letters.

Activity B: Counting the number of 1's in a string of 0's and 1's. If enter the correct number, then you will get 1 point and a new array of numbers will be randomly generated for you to count. If your answer is incorrect, then you will not get any points and will still have the same array of binary numbers for you to count. There is no limit to the number of attempts for each array. This is a activity — you get no money for the points!

Round SAT (8 minutes):

Activity A: Answering SAT questions. You will pick one of two sets of multiple choice questions. You will get paid 40 points per correct answer and will lose 10 points for incorrect answers. Your points are accumulated as you go and are shown on the screen. You will get to see 1 question at a time which you will be able to answer. Once you have answered a question you will NOT be able to change it, so you choice is always final.

Annoyance:: Except for the first question, some letters of the text will be missing. With a certain probability each letter will be dropped from each SAT question. As usual, you can press the button that takes you to activity B at any moment of the round.

Activity B: In this case the B activity will be the same SAT text, except it will have all the letters in the text, and it will pay you 10 points per correct answer and subtract 2 points if the answer is incorrect. If you switch to activity B you will start at the same point where you decided to change from A to B. So, for example, if you decided to switch at question 3, you will start activity B at question 3. Note that you can come out with negative earnings from this activity.

Movie/Pay (8 minutes):

Activity A: In this round you will be offered to pick from a series of clips to watch. On top of this you will be endowed with 500 points for you to keep.

Annoyance: Some seconds into the video you will be asked to pay a fee (in experimental points) if you want to continue watching the video.

Activity B: If you don't pay, the video will switch to waves breaking at La Jolla beach.

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