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Beyond Sample Error

Greg Barron   Giovanni Ursino

IEIL0054 - November - 2009

UNIVERSITA' CATTOLICA DEL SACRO CUORE
- Milano -

QUADERNI DELL'ISTITUTO DI ECONOMIA DELL'IMPRESA E DEL LAVORO

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n. 54 – novembre 2009

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Istituto di Economia dell'Impresa e del Lavoro
Facoltà di Economia
Università Cattolica del Sacro Cuore
Largo Gemelli, 1 - 20123 Milano

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* La Redazione ottempera agli obblighi previsti dalla Legge n. 106 del 15.04.2006, Decreto del Presidente della Repubblica del 03.05.2006 n. 252 pubblicato nella G.U. del 18.08.2006 n. 191.

Underweighting Rare Events in Experience Based Decisions: Beyond Sample Error

Greg Barron* and Giovanni Ursino†

November 5, 2009

Abstract

Recent research has focused on the "description-experience gap": While rare events are overweighted in description based decisions, people tend to behave as if they underweight rare events in decisions based on experience. Barron and Erev (2003) and Hertwig, Barron, Weber, and Erev (2004) argue that such findings are substantive and call for a theory of decision making under risk other than Prospect Theory for decisions form experience. Fox and Hadar (2006) suggest that the discrepancy is due to sampling error: people are likely to sample rare events less often than objective probability implies, especially if their samples are small. The current paper examines the necessity of sample error in the underweighting of rare events. The first experiment shows that the gap persists even when people sample the entire population of outcomes and make a decision under risk rather than under uncertainty. A reanalysis of Barron and Erev (2003) further reveals that the gap persists even when subjects observe the expected frequency of rare events. The second experiment shows that the gap exists in a repeated decision making paradigm that controls for sample biases and the "hot stove" effect. Moreover, while underweighting persists in actual choices, overweighting is observed in judged probabilities. The results of the two experiments strengthen the suggestion that descriptive theories of choice that

*Harvard Business School

†Universitat Pompeu Fabra and Catholic University of Milan. This paper was written while the author was visiting fellow at the Department of Economics at Harvard University.

assume overweighting of small probabilities are not useful in describing decisions from experience. This is true even when there is no sample error, for both decisions under risk and for repeated choices.

JEL Classification Numbers: D81, C91

Keywords: Experience-based decisions, Prospect Theory, rare event, overweighting, underweighting

1 Introduction

Several recent papers have focused on the description-experience gap, the observation that while people tend to overweight small probabilities in decisions from description, they appear to underweight small probabilities in decisions from experience. Fox and Hadar (2006) (hereafter FH) note that, in Hertwig, Barron, Weber, and Erev (2004) (hereafter HBWE), behavior that appears to reflect underweighting can be explained by statistical sampling error; it follows from the binomial distribution that people are more likely to under-sample rare events then to over-sample them. FH demonstrate that the two-stage choice model (Fox and Tversky (1998)) that assumes that choice can be predicted from estimated probabilities can account for HBWE's finding when observed frequencies are substituted for the underlying probabilities. This paper's main goal is to examine the usefulness of FH's account in explaining underweighting of rare events beyond the HBWE paradigm.

As FH point out, while decisions from description are decisions under risk (as the lotteries are known) decisions from experience are often decisions under uncertainty when the lotteries are represented as unlabeled buttons. Underweighting of rare events has been observed in two different paradigms under uncertainty. In the first, Repeated Decision Making (as in Barron and Erev (2003); Erev and Barron (2005)), people repeatedly choose between two unmarked buttons, each representing a static lottery. After each choice one outcome is drawn from the chosen distribution and is added or subtracted from the subject earnings. In the second paradigm, Free Sampling (as in HBWE), two unmarked buttons again represent static lotteries. However, subjects only make a single choice between the two options. Before they choose, subjects are allowed to sample outcomes from the two buttons as often as they wish without incurring actual gains or losses. Once satisfied with their search, subjects make a single choice and one outcome is drawn from that button's associated distribution. These two paradigms, while different from each other, have in common the incremental acquisition of information over time about the underlying lotteries. Additionally, both paradigms demonstrate decision making under knightian uncertainty. They do not constitute decisions under risk since, no matter how many outcomes are sampled, there will be heterogeneous beliefs about the underlying distributions that remain unknown (Fox and Hadar (2006)).

This paper contributes to the existing literature on the description-experience gap in two main ways: as the underweighting of rare events has been observed in both the repeated choice paradigm and the free sampling paradigm we examine the role of statistical sampling error in both contexts. First, in Experiment 1 we introduce a version of the sampling paradigm that specifically examines decisions under risk, where the underlying choice distributions become known through the sampling process. This paradigm allows us to examine not only the predictions of the two-stage model, but also those of Prospect Theory since the decisions are made under risk. Secondly, we turn to the repeated choice paradigm through a re-examination of the repeated choice data from Barron and Erev (2003) while controlling for sample error. Finally, in Experiment 2 we examine a repeated choice task designed to be free of sampling error. The results of the two experiments and the new analysis of past data all demonstrate the underweighting of rare events in decisions from experience, *i.e.*, the description-experience gap, even in the absence of statistical sample error. These results suggest that sample error, while being sufficient for the observed underweighting in HBWE, is not necessary for underweighting to occur in decisions form experience. The results remain consistent with Hertwig, Barron, Weber, and Erev (2004) 's explanation; that underweighting is due to over reliance on small samples drawn from memory (Kareev (2000); Barron and Erev (2003); Erev and Barron (2005); Hertwig, Barron, Weber, and Erev (2004)).

2 Experiment 1: decisions under risk using a sampling paradigm

Sampling error plays a role in the "sampling paradigm" due to the paradigm's uncertain nature. No matter how many outcomes are sampled, beliefs will remain heterogeneous as to the underlying distribution. One way to control for this, that we explore here, is to employ sampling without return from a finite population. In other words, the decision maker gets to see all the outcomes one at a time. Once the entire population of outcomes has been sampled the decision maker has full information about the prospects' outcomes and their likelihoods. Any choice based on this information (about drawing a single outcome form two such populations) will be *a decision under risk*. If the description-experience gap is indeed driven by sample error, it should not be observed when the entire population has been exhaustively sampled. Alternatively, if the over reliance on small samples drawn from memory plays a significant role in decisions from experience, a gap should still be observed.

2.1 Method

One hundred twenty one students of the Boston area served as paid volunteers in the experiment. Students were at the undergraduate or graduate school level and came from local universities (Harvard, Boston University and Boston College).

During each session participants went through two conditions "10%" and "20%", that were identical with the exception of the risky lottery. The order of the two conditions was randomized. Each condition consisted of two phases. In the first phase, described below, we identified a pair of lotteries for which the participant was indifferent and in the second phase the participant made a single choice between the lotteries. The choice was made either from Description or from Experience (our two between-subjects conditions). Table 1 shows the overall design of the experiment. Participants were paid according to one of the four phases they went through, randomly chosen at the end of the experiment. Participants also received a $10 show up fee and the average total payment was $27.20.

Table 1: Design of Experiment 1

Condition	Description (between)	Experience (between)
10% (within)	Phase 1 and Phase 2	Phase 1 and Phase 2
20% (within)	Phase 1 and Phase 2	Phase 1 and Phase 2

Phase 1 was a BDM-like procedure (Becker, DeGroot, and Marschak (1964)) meant to elicit the value, X, for which participants were indifferent between the relatively safe (S) and risky (R) lotteries below:

- S:($X, 0.9; 0) or R:($40, 0.1; 0) in Condition 10%
- S:($X, 0.8; 0) or R:($20, 0.2; 0) in Condition 20%

The probabilities of 0.1 and 0.2 were chosen keeping with the values for which over and underweighting are typically observed in decisions from description and from experience. To arrive at the point of indifference, X_indiff, each participant sequentially chose between pairs of lotteries, as above, with alternative values for X. X randomly started out at either 0 or 40 (0 and 20 for Experiment B) and then increased by half the range if R was preferred and decreased by half the range otherwise. After the thirteenth choice we were able to identify the implied indifference point for each subject. Participants were told that their Phase 1 payoff would be an outcome drawn from their preferred lottery in a randomly selected pair, chosen from the 13 pairs they were presented with. The outcome was not shown until the end of entire session. We employed this procedure in an effort to control for heterogeneity in preferences for risk. Thus, any difference in choices in the next phase can only be traced to the difference in the two conditions in Phase 2 and will not be influenced by pre-existing preferences over particular lotteries.

In Phase 2 of each experiment participants were randomly allocated between a Description and an Experience condition, between subjects, and made an actual decision between ($X_indiff -$0.02, 0.9) and R:($40, 0.1) (or ($X_indiff -$0.02, 0.8) and R:($20, 0.2) for condition 20%). We subtracted 2 cents from X_indiff to avoid participants feeling committed to their previously indicated indifference point. We did not expect such a small amount to have a large effect on the choices in Phase 2 although it arguably induces a preference for the risky lottery.

Participants in the Description condition made a single choice between the two prospects that were described as in the previous paragraph. In the Experience condition participants were not shown the lotteries. Instead, they were presented with two unmarked buttons and were told that they corresponded to two boxes containing 100 balls each. Each ball was marked with one of only two possible outcomes for each box. They were then instructed to sample from each box (by clicking on the two buttons in any order they desired) all the balls and to observe their values, one by one until both boxes were empty. The boxes would then be refilled with the same balls and they would choose a box from which to draw a single ball for real money. They were provided with paper and pencil and could keep a tally throughout the experiment if they wished. After sampling all the outcomes subjects made a single choice based on their experience of the two distributions. Subjects did not receive feedback on the outcome until the end of the entire session. After both Phase 1 and 2 were completed, the procedure was repeated for the experiment not yet completed (10% or 20%). When all data collection had been completed subjects were shown their outcomes for Phases 1 and 2 of experiments A and B. Each outcome was a draw from the participants selected lottery for that phase (randomly selected among the thirteen pairs of the BDM procedure for Phase 1). One of these four outcomes was randomly chosen for the participants' payoff. This rule allowed us to make the BDM procedure incentive compatible while keeping the experiment financially affordable.

2.2 Results

Table 2 shows the mean choice of the risky lottery R in all 4 conditions. Aggregating over both 10% and 20%, the proportion of Risky choices in the Experience condition (38%) was significantly lower than in the Description condition (56%) ($\beta = 1.53$, z=2.59, p<0.01, first row in logistic regression of Table 3). There was no significant difference between conditions 10% and 20% nor was there an effect of the order the conditions were presented or of the indifference point selected by the participant (rows 2-4 of Table 3, all non significant). This result is consistent with the description-experience gap and implies underweighting of the rare event in a decision under risk and in the absence of sampling error.

Table 2: Mean Choice of R

Condition	Description	Experience
10%	0.52	0.35
20%	0.59	0.4

Table 4 reports the proportion of choices correctly predicted by Prospect Theory in all the conditions. The prediction was calculated per each subject using the parameters estimated in Tversky and Kahneman (1992) and the (modified) X_indiff taken from the BDM procedure of Phase 1. The prediction was then com-

Table 3: Logistic Regression

Choice of R (dependent)	Coef.	StdErr	z	P> $|z|$	95% Conf. Int.	
Description	1.53	0.59	2.59	0.01	0.37	2.68
10%	-0.26	0.27	-0.98	0.33	-0.79	0.26
Order (10% first=1)	0.29	0.27	1.08	0.28	-0.23	0.81
X_indiff	-0.003	0.05	-0.06	0.95	-0.1	0.1
X_indiff Description	-0.13	0.09	-1.41	0.16	-0.3	0.05
Constant	-0.51	0.39	-1.29	0.2	-1.28	0.26

pared to that subject's behavior. As can be seen in the table, Prospect Theory is significantly more useful in predicting the decisions from description than those from experience even though both decisions were decisions made under risk.

Table 4: Proportion predicted by PT

Condition	Description	Experience
10%	0.62	0.38
20%	0.61	0.42

3 Repeated choice vs. free sampling

Less clear is the role of sampling error in the *repeated choice paradigm*. The paradigm is arguably quite prevalent in real life settings where we learn from the outcomes of our previous choices and most learning models have been developed with the explicit goal of understanding this process. While sampling per se is not an issue in this paradigm, since outcomes are incurred and not merely sampled, the statistical phenomenon of sampling error and its effect on decision making remain an issue.

Simple learning models of repeated choice predict that underweighting of rare events will occur due to an over reliance on small samples (Barron and Erev (2003); Erev and Barron (2005)) and/or due to the "hot stove" effect (Denrell and March (2001)) where a bad outcome decreases choice from the same distribution again in the future. In both cases, while the models predict that sample error can increase the apparent underweighting of rare events, they also predict that underweighting will persist even in the absence of sampling error. These predictions stand in contrast to the account of underweighting given by FH in which underweighting should disappear when sample error is controlled for. The remainder of this paper examines this hypothesis in both a reanalysis of the Barron and Erev (2003) repeated choice data and a laboratory experiment.

3.1 Revisiting the Barron and Erev (2003) data

If sample error is the prime mechanism driving the gap between experience and description based decisions, the gap should disappear when we examine subjects who observed the rare event approximately the expected number of times. To evaluate this assertion we identified the 6 problems studied by Barron and Erev (2003) for which the analysis is relatively straight forward. The 6 lottery pairs, and their problem number from the Barron and Erev (2003) paper, appear in Table 5. Each pair includes one risky two-outcomes lottery and one safe certain-outcome lottery. The lottery with the higher expected value (H) appears in second column and the lottery with the lower expected value (L) appears in the third column. The fourth column shows the proportion of H choices aggregated over subjects and over 400 trials. As noted in Barron and Erev (2003), behavior in each of the problems is consistent with underweighting of the rare event and is inconsistent with Prospect Theory (assuming the parameters estimated in Tversky and Kahneman (1992)).

To examine the behavior of those subjects whose observed sample of outcomes was relatively unbiased we first computed, for each individual, the observed frequency of the rare event in the risky lottery. We then removed all subjects whose observed frequency of the rare event was greater or less then one standard deviation from the expected frequency. The remaining number of subjects appears in the right most column of Table 5.

As shown in column 5 of the table, in 4 of the 6 problems the proportion of H choices in the restricted data set did not change significantly. In two of the 6 problems, 8 and 9, the less biased subjects chose H significantly more often. However, even in these two problems the choice of the modal subject was the same as that in the unrestricted data set (*i.e.*, they continued to choose L most of the time).

Table 5: Barron and Erev (2003) decision problems

	Proportion of H choices				
Problem	H	L	B&E P(H)	+/- 1std. P(H)	N (from 24)
4	4, .8	3	0.63	0.64	10
6	-3	-4, .8	0.6	0.56	15
7	10, .9	9	0.56	0.63	20
8	-10, .9	-9	0.37	0.47*	17
9	32, .1	3	0.27	0.43*	11
11	-3	-32, .1	0.4	0.33	11
* p<0.05					

In summary, the reanalysis of the repeated choice paradigm in Barron and Erev (2003) does not support FH's argument that what appears to be underweighting of rare events is in fact primarily the result of sample error. Even when observed outcomes approximate expected distributions, behavior remains consistent with the underweighting of small probabilities.

Three shortcomings of the above analysis need to be addressed. First, the analysis performed was not particularly sensitive. Observed frequencies of the rare event still fluctuated in the +1/-1STD range for individual subjects, each of whom was incurring a different stream of payoffs from choosing safe and risky options. Secondly, the stream of observed payoffs was path dependent since subjects only observed the outcome from the chosen option (*i.e.*, forgone payoffs were not observed). Underweighting in this case can be the result of the "hot stove effect" which effectually leads to a biased sample as people cease to choose an option after an unlucky streak of bad outcomes. Thirdly, subjects were not asked to estimate the probability of the rare event. Thus, we still don't know if any judgment error has occurred and can not directly test the predictions of the two-stage choice model that uses estimations to predict choice. We address all these limitations in an experiment using the repeated choice paradigm where all subjects observe the same stream of incurred and forgone payoffs. Additionally, the complete stream of payoffs is representative of the underlying payoff distributions and we elicit probability judgments of the rare event.

3.2 Experiment 2: repeated choice and judgment

3.2.1 Method

Each subject in the study performed both a binary choice task and a probability assessment task. The binary choice task was performed under uncertainty one hundred times (with immediate feedback on both obtained and forgone payoffs) with the probability assessment task following each choice in rounds 51-100. Upon completion, participants performed a one-time retrospective probability assessment task.

In the binary choice task, participants chose between two unmarked buttons presented on the screen. Each button was associated with one of two distributions referred to here as S (for safe) and R (for risky). The S distribution provided a certain loss of 3 points while the R distribution provided a loss of 20 points with probability 0.15 and zero otherwise. Thus, the two distributions had equal expected value and the exchange rate was 100pts = 1 Shekels (about 29 US cents).

To assure that all subjects experienced the same representative sequence of outcomes we first produced random sequences of 100 outcomes and the first sequence with an observed probability of 0.15 for the -20 outcome was used for all participants. The sequence provided the -20 outcome on rounds 12, 15, 19, 20, 21, 23, 25, 35, 40, 41, 60, 73, 80, 87, and 96.

In the probability assessment task, performed after each binary choice in trials 51-100, participants were prompted to estimate the chances (in terms of a percentage between 0 and 100) of -20 appearing (on the R button) on the next round.

After completing 100 rounds participants were asked to estimate ("end-of-game estimates"), to the best of their recollection, two conditional subjective probabilities (SP): (1) the chances of -20 appearing after a previous round with a -20 outcome [SP(-20|-20)] and (2) the chances of -20 appearing after a previous round with a 0 outcome [SP(-20|0)].

Twenty-four Technion students served as paid subjects in the study. Most of the subjects were second and third year industrial engineering and economics majors who had taken at least one probability or economics course. In addition to the performance contingent payoff, described above, subjects received 28 Shekels for showing up. The final payoff was approximately 25 Shekels (about 5 US dollars).

Subjects were informed that they were operating a "computerized money machine" but received no prior information as to the game's payoff structure. Their task was to select one of the "machine's" two unmarked buttons in each of the 100 trials. In addition, they were told that they would be asked, at times, to estimate the likelihood of a particular outcome appearing the following round. As noted above, this occurred in trials 51-100.

Subjects were aware of the expected length of the study (10-30 minutes), so they knew that it included many rounds. To avoid an "end of task" effect (*e.g.*, a change in risk attitude), they were not informed that the study included exactly 100 trials5. Payoffs were contingent upon the button chosen; they were produced from the predetermined sequence drawn from the distribution associated with the selected button, described above. Three types of feedback immediately followed each choice: (1) the payoff for the choice, which appeared on the selected button for the duration of 1 second, (2) payoff for the forgone option, which appeared on the button not selected for the duration of 1 second and (3) an update of an accumulating payoff counter, which was constantly displayed.

3.2.2 Results

The mean probability assessment from trials 51-100, aggregated over trials and over subjects, was 0.27. This value is significantly larger than 0.163, the mean running average of the observed probability of the -20 outcome ($t[23] = 3.11$, $p < .01$). Thus, the results reflect overestimation of the rare event.

As shown in Table 6, participants' aggregate proportion of R choices was 0.74 (significantly larger than 0.5, $t[23] = 7.47$, $p < .001$). This result is consistent with the assertion of underweighting of rare events in choice. The rate of R choice over trials 51-100 was 0.80 (significantly larger than 0.5, $t[23] = 6.78$, $p < .001$).

Comparison of the judgment and the choice data for trials 51-100 is inconsistent with FH's account for underweighting. While subjects' choices are consistent with underweighting the rare event, they consistently overweighted the rare event in their probability estimations. While the objective probability of the rare event was 0.15 and its mean observed proportion (recalculated after each trial) was 0.16, subjects mean estimation was 0.27 reflecting significant overweighting. This pattern cannot be predicted by the two stage choice model that applies Cu-

Table 6: A summary of the aggregate results of Experiment 2

Statistic	Trials 1-100	Trials 51-100
P(R) proportion of R choices	0.74 (0.5*)†	0.8 (0.5*)†
SP(-20) Mean subjective assessment of the probability of a -20 outcome	–	0.27 (0.16*)†
*p<0.01 † The numbers in parenthesis denote the null hypotheses for the test reported in the text. All t-tests are one-sample tests unless otherwise noted.		

mulative Prospect Theories weighting function[1]. Applying that function, which assumes overweighting of small probabilities, to the objective, the observed *or* the estimated probabilities leads to a prediction of overweighting in choice, and not underweighting as was observed.

In order to confirm that the different reactions occur at the level of individual subjects a pair-wise within-subjects analysis was performed. For 63% (15/24) of the participants, assessment and choice results were not consistent in terms of the implied weighting of the -20 outcome. Overestimation and underweighting of rare events was found to occur in 100% of these 15 cases.

4 Discussion

We examine FH's assertion that decisions reflecting the underweighting of rare events may be the result of statistical sample error. As HBWE point out, rare events are more likely to be under sampled than oversampled due to skewness of the binomial distribution. To see if sample error is a necessary condition for underweighting to occur, we present two experiments and one re-analysis of past data that control for, or eliminate the possibility of sample error. In all three data sets behavior continued to be consistent with the underweighting of rare events in decisions form experience. This paper's first contribution is in showing that while

[1]There are parameters for which Prospect Theory's weighting function will imply underweighting of rare events. However, such parameterization is a contradiction to the fourfold pattern of risk attitudes observed in decisions form description. It is this pattern that the model was offered to elegantly quantify in the first place.

sample error may be sufficient for implied underweighting to occur, it is clearly not a necessary condition.

The findings shed some light on the distinction between decisions form experience and from description. It is tempting to classify the former as a decision under uncertainty and the latter as a decision under risk. However, in Experiment 1 we examine a hybrid paradigm where a decision from experience is taken under risk as all the outcomes and their frequencies were known by the decision maker. The significant description-experience gap that was observed is inconsistent with models that assume overweighting of rare events under risk (*i.e.*, Prospect Theory).

One remaining possibility is that people are making a judgment error, even if the sample is unbiased, and are underestimating the rare event. Experiment 2 examined this possibility by eliciting probability estimates throughout the experiment. While there was indeed a judgment error, it was in the opposite direction. People were overestimating the rare event while their choices (within subject) reflected underweighting. Again, this pattern of results cannot be predicted by models that assume Prospect Theory's weighting function such as the Two-stage choice model (Fox and Tversky (1998)). Overweighting of estimations (e.g., Viscusi (1992); Erev, Wallsten, and Budescu (1994)) and underweighting in choice have both been demonstrated in other research, but never concurrently and within subject.

Decisions from experience remain qualitatively different than decisions from description in ways beyond subjects' tendency to under sample lotteries, as was the case in Hertwig, Barron, Weber, and Erev (2004) sampling paradigm. All the data presented in the current paper are consistent with the assumption that decisions from experience rely on small samples drawn from memory and can be described by simple learning and sampling models that quantify this assumption.

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