Anchoring Bias in Relationship Between Objective and Subjective Probability

Atsuo Murata

Okayama University, Okayama, Japan

This study empirically identified the relationship between the objective and the subjective probability and confirmed whether the relationship corresponded with the hypothesized weighting function proposed in prospect theory. As a result, it was found that the experimentally identified relationship between the objective and the subjective probability corresponded with the hypothetical weighting function in prospect theory. In other words, the estimated number of deaths was underestimated for moderate and high number of deaths, while the estimated number of deaths was overestimated for the small or rare number of deaths. Moreover, in order to clarify how cognitive bias occurred in the estimation of number of deaths for a variety of deaths and accidents, it was examined whether the different anchor biased the relationship above. The estimated numbers of deaths were remarkably affected by the anchor (initial information available for estimation), and the estimated numbers of deaths for the group given the anchor A (large number of deaths) were larger than that for the group given the anchor B (small number of deaths). Some implications for risk management were given from the perspective of cognitive biases.

Keywords: subjective probability, underestimation, overestimation, prospect theory, anchoring bias

Introduction

Our cognitive information processing is conducted by System 1 or System 2. While System 2 requires us to conduct effortful, demanding and deliberate mental activities, System 1 operates quickly, automatically, without time consuming, and intuitively with little or no efforts. Although heuristic approaches that we adopt when we have no time to deliberate are based on System 1, and are very simple and intuitive, it is possible that such approaches fall into a trap of cognitive biases. Due to bounded rationality (Kahneman & Tversky, 1984; Kahneman, 2011; Tversky & Kahneman, 1974; Altman, 2012; Angner, 2012; Bazerman & Moore, 2001), we generally cannot make decision rationally, and inevitably suffer from cognitive biases. Kahneman (2011), Tversky and Kahneman (1974), and Kahneman and Tversky (1984) proposed prospect theory to explain such cognitive biases in decision making under uncertainty. In prospect theory, the weighting function of objective probability such as number of deaths per year for each cause is hypothesized so that the weight is larger for the small probability range, and the weight is smaller for the large probability range. Such a hypothesis is based on the study by Lichtenstein, Slovic, Fischhoff, Layman, and Combs (1978). Thus, it should be further verified whether such a hypothesis is proper or not even in different populations.

After some serious accident occurred, we tend to overestimate the occurrence probability of such an

Atsuo Murata, professor, Department of Intelligent Mechanical Systems, School of Natural Science and Technology, Okayama University.

accident. For example, we hesitate to get on an airplane immediately after a serious aviation accident due to the overestimation of a fatal aviation accident. This means that our psychological evaluation of probability, that is, subjective probability (Wright & Ayton, 1994) changes irrespective of the constant objective probability of airplane crash. Therefore, it is important to identify the relationship between the objective and the subjective probability properly, and make clear how our psychological evaluation of probability or risk is deviated from the objective probability or risk.

The anchoring bias is pointed out (for example, Kahneman (2011) and Bazerman and Moore (2001)). It is predicted that the difference of the anchor (initial information available for the evaluation) easily changes the relationship between the objective and the subjective probability above. However, such analyses have not thoroughly conducted. If such a hypothesis was verified, this gives us a lesson that our decision-making is easily distorted by such insignificant information initially available for decision-making. If so, we must be very cautious in the assessment of risks (in a sense, subjective probability). It is possible that ignoring such characteristics and improperly assessing a risk lead to crucial accidents such as the challenger space shuttle disaster (Reason, 1990; Vaughan, 1997).

This study firstly empirically identified the relationship between the objective and the subjective probability, and it was confirmed whether the relationship corresponded with that found by Lichtenstein et al. (1978) even for the different population. Secondly, it was explored whether the different anchor biased the relationship above.

Problems and Aim

Our psychological evaluation of probability (subjective probability) changes irrespective of the constant objective probability of events such as an airplane crash. Moreover, this relationship might be affected by changing initially available information (anchor). As we judge the probability or risk not rationally but irrationally, it is important to identify the relationship between the objective and the subjective probability properly, and clarify our irrational characteristics. Ignoring such characteristics and assessing a risk improperly lead to a crucial accident such as the Challenger space shuttle disaster. Thus, the understanding of our cognitive bias in evaluating the probability and its susceptibility to the change of anchor (initial available information) is very important so that we can take some countermeasure to remove such a cognitive bias and prevent such a crucial accident, which stems from our distorted decision-making, from occurring.

Method

Participants

Sixty participants took part in the experiment. They were all undergraduate students at Faculty of Engineering. After a brief explanation of the aim and contents of the experiment were given to the participant, we received informed consent from all participants.

Experimental Task

The participants were distributed a paper on which 21 causes of deaths in Table 1 were randomly arranged. Their task was to estimate the number of deaths for each cause. The participants were instructed to estimate the number of deaths during 2012 in Japan.

Design and Procedure

The participants were equally divided into three groups. The first group was not provided with the cue for

estimation. Two other groups were given the anchor (cue for estimation). One group was given the cue (anchor) A for estimation. Another group was provided with the cue (anchor) B for estimation. The anchors A and B were as follows.

Anchor A: The number of deaths per year due to stroke is 121,602.

Anchor B: The number of deaths per year due to flood is 35.

Research Hypothesis

The first hypothesis was that the estimated number of deaths was underestimated for moderate and high number of deaths, while the estimated number of deaths was overestimated for the small or rare number of deaths. The second hypothesis was that the estimated numbers of deaths were remarkably affected by the anchor, and the estimated numbers of deaths for the group given the anchor A were larger than those for the group given the anchor B. In other words, we hypothesized that the anchor distorted the estimation of number of deaths.

Results

Relationship Between Objective and Subjective Probability

The relationship between objective and subjective probability obtained from the experiment are summarized in Figure 1. In Table 1, the causes of deaths for numbers from 1 to 21 are listed. The smaller number in Table 1 shows that many numbers of deaths are induced by these causes. The larger number in Table 1 means that there are few deaths due to these causes. If the subjective probability judgments (estimations) were accurate, the subjective probability would equal the statistical data (actual number of deaths for each cause). Although the data were dispersive to some extent, it tended that the rare causes whose actual numbers of deaths are small (for example, numbers 15, 16, 17, and 18) were overestimated. Contrary to this tendency, the common causes of death (for example, numbers 1, 2, 3, 4, and 5) tended to be underestimated.

Figure 1. Relationship between estimated (predicted) number of deaths and the actual number of deaths (Japanese statistical data in 2012). If the estimated and the actual number of deaths are equal, the data fall on the straight line.

Table 1

Correspondence Between Cause of Death and Numbers in Figure 1

1	All cancer	8	Renal failure	15	Childbirth accidents
2	Heart disease	9	Liver disease	16	Flood
3	Pneumonia	10	Disabetes	17	Electrocution
4	Stroke	11	Seasonal flu	18	Food poisoning
5	Disease due to air pollution	12	Motor vehicle accidents	19	Tomado
6	All accidents	13	Murder	20	Helicopter crash
7	Suicide	14	Climbing accidents	21	Radioactivity accidents

Anchoring Bias

The estimated numbers of deaths for the group given the anchor A tended to be larger than those for the group given the anchor B. Anchoring information was found to distort the subjective probability. In Figure 2, the estimated number of deaths is compared among three conditions (Anchor A, Anchor B, and No anchor). In Figure 3, the difference between the mean actual number of deaths and the mean estimated number of deaths is compared between the underestimation and the overestimation areas in Figure 1 or Figure 2, and among three conditions (Anchor A, Anchor B, and No anchor). Here, the mean actual number of deaths corresponds to the mean of all number of deaths belonging to underestimation or overestimation areas. The mean estimated (predicted) number of deaths corresponds to the mean of all predicted number of deaths belonging to underestimation or overestimation areas. The underestimation area corresponds to the numbers 1-14 in Table 1. The overestimation area includes the numbers 15-21 in Table 1.

Figure 2. Relationship between estimated (predicted) number of deaths and the actual number of deaths (Japanese statistical data in 2012) as a function of anchoring condition (Anchor A, Anchor B, and No anchor).

As for the overestimation area, a statistical t -test conducted on the number of deaths revealed significant differences between actual and estimated number of deaths for all of three conditions (Anchor A: $|t| = 4.621$, $p < 0.01$, Anchor B: $|t| = 3.896$, $p < 0.01$, and No anchor: $|t| = 4.416$, $p < 0.01$). As a result of carrying out a similar t -test for the underestimation area, significant differences between actual and estimated number of deaths were also detected for all of three conditions (Anchor A: $|t| = 2.647$, $p < 0.05$, Anchor B: $|t| = 7.624$, $p < 0.01$, and No anchor: $|t| = 4.241$, $p < 0.01$). As hypothesized, both the overestimation and the underestimation tendencies were statistically verified for three conditions.

Figure 3. Difference between the mean actual number of deaths and the mean estimated number of deaths compared between the underestimation and the overestimation areas, and among three conditions (Anchor A, Anchor B, and No anchor).

Discussion

Relationship Between Objective and Subjective Probability

The probability weighting as shown in Figure 4 is generally assumed in prospect theory (Kahneman, 2011; Tversky & Kahneman, 1974; Kahneman & Tversky, 1984), which aims at explaining cognitive biases such as reversal of preference and loss aversion in decision-making under uncertainty. The probability weighting function (Wakker, 2011) in Figure 4 is given by

$$w(p) = \frac{p^c}{(p^c + (1-p)^c)^{1/c}} \quad (1)$$

where p is the objective probability without weighting, and c is an empirically determined parameter. When c equals 1, this corresponds to the diagonal line, which means that the probability weighting (subjective probability) is equal to the objective probability. For other values of c ($= 0.4, 0.6$, and 0.8), the probability weighting for the low objective probability is overestimated, while the probability weighting for the high objective probability is underestimated.

Figure 4. Typical and hypothetical probability weighting function assumed in prospect theory.

In prospect theory, the weighting function of objective probability such as number of deaths per year for each cause is hypothesized so that the weight is larger for the small probability range, and the weight is smaller for the large probability range. Such a hypothesis is based on the study by Lichtenstein, Slovic, Fischhoff, Layman, and Combs (1978).

As shown in Figures 1 and 2, the number of deaths tended to be overestimated for the rare causes whose actual numbers of deaths are small (for example, numbers 15, 16, 17, and 18). The number of deaths was underestimated for the common causes of death (for example, numbers 1, 2, 3, 4, and 5). This corresponded well with Lichtenstein et al. (1978).

Anchoring Bias

Anchoring is related to an adjust-and-anchoring heuristic for estimating uncertain quantities like the prediction of number of deaths for a variety of accidents or diseases. The adjust-and-anchoring bias seems to stem from confirmation heuristics (Bazerman & Moore, 2001). Confirmation bias can be generally explained as follows. We tend to focus on a single possible cause of an effect, neglect alternative causes of the effect, and conclude that the association between the single cause and the effect is stronger than it actually is.

The adjustment typically ends prematurely, and leads to under- or over-estimation as shown in Figures 1 and 2. The cue (anchor) A or B in this study readily distorted the decision (estimation of number of deaths). When we provide the participants with a rare case (small number of deaths such as “The number of deaths per year due to flood is 35”), they tended to be affected by this number and underestimate the number of deaths for a variety of deaths or accidents. When the participants were provided with a common case (large number of deaths such as “The number of deaths per year due to stroke is 121,602”), they tended to be affected by this

number and overestimate the number of deaths for a variety of deaths or accidents. These tendencies are demonstrated in Figure 2. When the larger number of deaths is given as a cue, the relationship between the probability and the probability weighting (subjective probability) moved upward. When the smaller number of deaths is given as a cue, the relationship between the probability and the probability weighting (subjective probability) moved downward.

It might be inferred that the cue functioned as priming. The cause of such a cognitive bias might be interpreted as follows. While we frequently encounter the rare events such as tornado or helicopter crash on TV or newspaper, we seldom encounter the common events of deaths such as strokes on TV or newspaper. This difference of availability to information between two cases must cause the distortion, and move the estimation of smaller number of deaths and larger number of deaths to the overestimation and underestimation areas, respectively.

The cue (anchor) definitely affected the decision-making (estimation of number of deaths), and distorted the relationship between the probability and the probability weighting (subjective probability). This means that such minor information is important enough to affect our decision-making. We unexpectedly tend to overestimate the occurrence probability of an airplane accident immediately after a serious aviation accident due to the overestimation of a fatal aviation accident. This means that our psychological evaluation of probability changes irrespective of the constant objective probability of airplane crash. We must bear this in mind when evaluating risks which hide behind a variety of our activities.

Therefore, it is important to identify the relationship between the objective and the subjective probability properly. Without this, our decision-making unexpectedly suffers from cognitive bias, and is easily distorted. The basic source of cognitive biases is based on our cognitive characteristics, that is, bounded awareness. In risk management under uncertainty, we must bear such an anchoring bias in mind. We are easily biased by the anchor even when we engage in objective risk assessment tasks such as estimating the number of deaths for a variety of accidents or diseases.

Conclusions

In conclusion, the relationship between the objective and the subjective probability on which prospect theory is based was empirically found to be valid. Moreover, although the relationship between the objective and the subjective probability mentioned above did not change, it was found that the anchoring biases easily occurred by changing the cue (anchor) in estimating numbers of deaths for each cause.

Future research should explore whether or not such a bias can be removed somehow. Moreover, we should develop a systematic method for checking a variety of cognitive biases in order to prevent crucial accidents or human errors stemming from cognitive biases.

References

- Altman, M. (2012). *Behavioral economics for dummies*. John Wiley & Sons Canada, Ltd.
- Angner, E. (2012). *A course in behavioral economics*. Palgrave Macmillan.
- Bazerman, M. H., & Moore, D. A. (2001). *Judgment in managerial decision making*. Harvard University Press.
- Kahneman, D. (2011). *Thinking, fast and slow*. Penguin Books.
- Kahneman, D., & Tversky, A. (1984). Choices, values, and frames. *American Psychologist*, 34.
- Lichtenstein, S., Slovic, P., Fischhoff, B., Layman, M., & Combs, B. (1978). Judgment frequency of lethal events. *Journal of Experimental Psychology: Human Learning and Memory*, 4, 551-578.

- Reason, J. (1990). *Human error*. Cambridge University Press.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185.
- Vaughan, D. (1997). *The challenger launch decision: Risky technology, culture, and deviance at NASA*. University of Chicago Press.
- Wakker, P. P. (2011). *Prospect theory for risk and ambiguity*. Cambridge University Press.
- Wright, G., & Ayton, P. (1994). *Subjective probability*. Wiley.