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Human economic choice as costly information processing

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ABSTRACT

We develop and test a model that provides a unified account of the neural processes underlying behavior in a classical economic choice task. The model describes in a stylized way brain processes engaged in evaluating information provided by the experimental stimuli, and produces a consistent account of several important features of the decision process in different environments: e.g., when the probability is specified or not (ambiguous choices). These features include the choices made, the time to decide, the error rate in choice, and the patterns of neural activation.

The model predicts that the further two stimuli are from each other in utility space, the shorter the reaction time will be, fewer errors in choice will be made, and less neural activation will be required to make the choice. The model also predicts that choices with ambiguity can be made more quickly and will require reduced neural activation in the horizontal intra-parietal sulcus than for choices with risk. Also, everything else being equal a larger value of certainty option in the choice will induce larger neural activation, and less experience on the part of the subject making choices will induce larger activation. We provide experimental evidence that is consistent with these predictions.

1. Introduction

We study a classical choice task collecting information on choices, reaction time, and brain activation to test a unified account of a decision maker's choice process. Our focus is on how subjects respond to different information available on the utility to them of the options offered to allocate mental effort in choice. Theories of economic choice have long ignored the fundamental role that effort can play in the decision process, though it has been hypothesized that choice requires an effort allocation.

We propose a random walk model of decision process with endogenous barriers as a function of effort that has a cost and produces benefits that vary with information quality. The model assumes that the decision maker first assesses the quality of the information available to him, determines the evidence required to decide (in the form of a criterion or threshold to be reached), and then processes this evidence to reach a decision. The subject continuously receives a pair of signals from each choice stimulus: When enough evidence is gathered so that the number of favorable comparisons for one of the choices reaches the threshold (as in a classical random walk, or drift–diffusion model of choice), the subject makes the choice. In summary, our model introduces choice of a costly effort into a standard drift–diffusion model, and tests its experimental implications.

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A critical element in this model is the notion of certainty equivalent. The certainty equivalent of a lottery is the monetary amount that makes the economic agent indifferent between the lottery and that amount. The certainty equivalent can be used to implement a cutoff policy: When the value of the certain amount is larger than the certainty equivalent, the subject will choose the certain amount; otherwise he will choose the lottery. The choice between two lotteries can similarly be considered as a comparison between two certainty equivalents. Thus we can think that the decision process consists of gathering information on certainty equivalents and then comparing them. It is this process that we will model and test with our experiments.

Questions related to ours have played a prominent role in economic experiments (Allais, 1953; Ellsberg, 1961; MacCrimmon et al., 1980; Kahneman and Tversky, 1979; Luce, 2000). Recently efforts have emerged in applying neuroscience methods to studying subjects making choices between such gambles,[1] but the determination and understanding of the process involving certainty equivalent cutoffs has not been part of those inquiries. In particular we will uncover cutoffs associated with risky and ambiguous lotteries as revealed by the choices of our subjects.

Previous studies of similar tasks have however uncovered two regularities in behavior and our model provides a possible explanation. The first regularity is: The closer the options are in value, the more frequent the error in choice (i.e., the frequency of error is higher near indifference.) The first description of such a finding in choice experiments was the seminal work Siegel (1964). A related effect in general decisions is the classical "symbolic distance" effect (Moyer and Landauer, 1967). Rustichini et al. (2005) recently elaborated this phenomenon for subjects in an fMRI experiment. In this case the further the choice is from indifference, the faster the reaction time. These two findings together may seem contradictory: We may observe more frequent errors close to indifference because the cost of error is less. But this explanation is difficult in light of the longer reaction time necessary to decide when the options are closer to indifference.

A second important regularity has recently surfaced in imaging studies. Rustichini et al. (2005) and Huettel et al. (2006) find that choices between ambiguous and certain amounts require less processing time than choices between risky and certain amounts. Our model leads to the prediction of such differences in reaction time and also predicts that relative brain activation will be more for risky than ambiguous gambles. The intuitive reason for this is that subjects at the moment of deciding how much effort to allocate in the evaluation process take into account the return to the effort, which is low in ambiguous choices, and thus terminate the process earlier.

In summary our model implies the closer to indifference an option is the more the response time, the more errors and the more brain activation. Furthermore we predict more response time and neural activation for risky than ambiguous choices. Our experimental results are consistent with this model.

2. Background

2.1. Choices under uncertainty

The economic theory of choice considers three different types of options: deterministic, risky, and ambiguous. A *deterministic* option is an outcome that will occur for sure, like a payment of $ 10. *Risky* options represent known probabilities of particular deterministic outcomes, for example, a 50/50 chance at $ 10 and $ 50. In an *ambiguous* option the probabilities of the outcomes are not known by the subject. For example, the deterministic outcomes of a risky gamble can be $ 10 and $ 50, with no statement of the chances of those outcomes. This leaves open the possibility of a lottery ranging from a 0% chance at $ 10 to a 100% chance at $ 10.

In experimental economics, it is assumed that subjects come to the experiment with an ordering on dollars (more are preferred to less), and then additional attempts to understand a subject's preferences proceed from there (Smith, 1982). Information about the relative preferences of a few options can be used to develop predictions about choices between other options. For example, suppose that option A is preferred to option B; then, an option in which there is a p chance ($0 < p < 1$) at A, and a $(1 - p)$ chance at B will be preferred to option B, but not to option A. Also, choices between options can be used to determine distance information between preferred options. Suppose we observe that a 50/50 chance at A and B is preferred to a 50/50 chance at C and D. Then if we also observe that a 50/50 chance at A and C is preferred to a 50/50 chance at B and D, we can conclude that A is preferred to D.

Such determinations of the implicit numerical properties of these stimuli were part of the constructions of Davidson et al. (1955) and were used to derive utility representations of various objects such as books, records, and grades of students as well as cigarettes for prisoners (Siegel et al., 1964). One point of the current paper is to test the hypothesis that evaluation projects options to an ordered line segment that can be interpreted as representing utility in economic choice studies (similar to numerical comparisons studied in Dehaene, 1999). Smith and Walker (2007) model choice as a productive activity, with returns and costs of making the choice taking the form of an additively separable utility function. A similar approach is outlined in several different approaches to behavioral economics (see Camerer and Hogarth, 1999; Johnson and Payne, 1985).

[1] For example, Breiter et al. (2001), Dickhaut et al. (2003), Huettel et al. (2005), Hsu et al. (2005), Rustichini et al. (2005).