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How can neuroscience inform economics?

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Neuroeconomics is now a well-established discipline at the intersection of neuroscience, psychology and economics, yet its influence on mainstream economics has been smaller than on the other two fields. This is in part because, unlike neuroscientists and psychologists, most economists are not interested in the process of decision making *per se*. We argue that neuroscience is most likely to influence economics in the short run by providing new insights into the relationships between variables that economists already study. In recent years the field has made many such contributions, using models from cognitive neuroscience to better explain choice behavior. Here we review the work that we think has great promise to contribute to economics in the near future.

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Introduction

Since its inception, the field of neuroeconomics has generated debate about when and how neuroscience can be used to inform the study of economics. Early articles outlined the exciting possibilities that cognitive neuroscience affords economists, with its huge amount of data and know-how regarding the processes of decision making [1]. A subsequent backlash questioned the value of using neuroscientific data to test models of economic choice [2]. A large body of ensuing work has taken more nuanced views, debating the pros and cons outlined in these seminal articles (e.g. [3,4•,5,6]). In this article we provide a selective survey of some of the recent directions in the field that we consider most likely to be of interest to mainstream economists in the near future. Note that by neuroeconomics we mean the study of data that shed light on the biological processes underlying economic choice, including reaction times, eye tracking, electroencephalography (EEG) and functional magnetic resonance imaging (fMRI).

In discussing the potential benefits of neuroscience for economics, we will largely allow the economics profession to 'set the rules', that is, to define the relationships which they hope to understand. Using the formulation of Bernheim [3] and Dean [5], we think of the economist as interested in developing models which define the relationship between some environmental parameters X and a set of economic behaviors Y. Such a model would take the form of a function $f: X \rightarrow Y$ which describes what behavior will occur in each possible environment. The fact that some underlying process, possibly mediated by some intermediate variables Z, governs this behavior is not of direct interest to the economist. So, for example, the fact that f is the composite of two functions, $h_1 : X \rightarrow Z$ and $h_2 : Z \rightarrow Y$, is not necessarily interesting to the economist: understanding h_1 and h_2 is useful only insofar as it helps to construct a better f. To take a concrete example, the act of choosing an alternative ($y \in Y$) from a budget set ($x \in X$) may in fact be the result of first a decision about which available alternatives to look at ($z \in Z$), and a subsequent choice from those considered alternatives. However, the economist is interested only in understanding the relationship between budget sets and choice — perhaps because data on what is looked at is not typically available to them in the situations they are keen to model. We take as given that the relationship between X and Y is not fully understood: once f is known, understanding the intermediate processes may no longer be of any use to the economist. The question then is what is the most efficient way to pursue the, as yet unknown, f?

In principle there are many ways in which understanding the process of choice could help economists to model the relationships they are interested in [3,4•,5]. The most widely accepted approach is inspiration: if a researcher discovers the form of h_1 and h_2, this implies a functional form for f which may constitute a new model that had not previously been considered. Observation of intermediate variables Z can also allow the researcher to 'break up the problem', and so test models of h_1 and h_2 separately, rather than model the composite function f: it may, for example, be easier to separately model the process which determines what is looked at, and the process of what is chosen conditional on what is looked at, rather than trying to model process of choice in one go. More controversially [3], data on intermediate processes has been used to test existing models of economic choice.

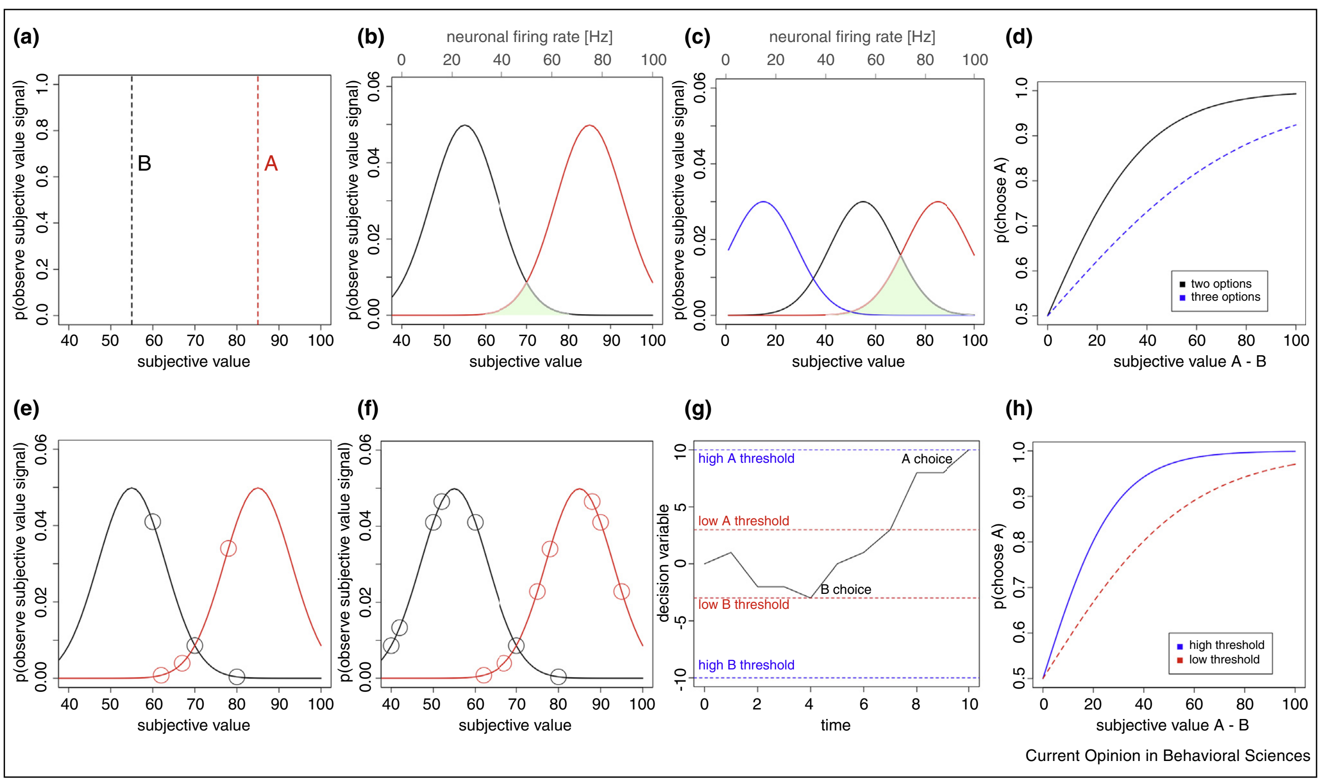
Rather than add to the large existing literature on the in-principle value of neuroeconomics, we present a selective survey of the current research in neuroscience that we believe may have implications for research in economics. These are mainly cases of 'inspiration' in which an understanding of neuroscience suggests new models relating variables that are of *a priori* interest to economists. We highlight the features of these research agendas that make them particularly likely to be relevant to economists.

The biological causes of stochastic choice

Perhaps the most fundamental relationship of interest to economists is that between the set of available alternatives and the choice made from that set: for example, what bundle of goods a shopper will choose in a supermarket, how much money a worker will save from their paycheck, or whether a young adult will choose to join the labor force or stay on in education.

The classic model of economic choice is one of deterministic preference maximization (Figure 1a). However, it has long been recognized that people tend to exhibit choices that are not internally consistent, and may appear stochastic: in two seemingly identical choice situations the same person may select different alternatives. Economists have developed models of stochastic choice based either on the concept of random fluctuations in utility, or choice errors (e.g. [7]). A standard approach is to employ either the logit or probit discrete choice models, which

Figure 1



Processes leading to stochastic choice. **(a)** Traditional economic choice models assume that people know their preferences so when choosing between two options A and B, one must simply compare the known subjective values and pick the higher one, in this case A. **(b)** Instead, people have noisy representations of these subjective values, encoded in neuronal firing rates. At any instant, the individual can receive value signals from the neuron(s) encoding A and B and compare them. The probability of receiving different signals is given (for example) by these probability distributions. If there is overlap of the distributions then there is some probability that the decision maker receives signals that lead him to make the incorrect choice, in this case B. **(c)** When a third, irrelevant option is added to the choice set, the range of subjective values expands, while the range of neuronal firing rates remains constant (with constant noise). Thus the same range of firing rates must cover a larger value range. This produces more overlap of the signal distributions for A and B (green shaded area), leading to an increased likelihood of error. **(d)** The black curve represents a standard logistic choice curve between A and B, without the presence of C. The blue dashed curve represents a choice curve of the probability of choosing A over B that results from the addition of C, with normalization. The presence of C increases the likelihood of error and thus flattens the choice curve. **(e,f)** In order to reduce errors, the decision maker may accumulate a few (e) or many (f) samples and compare the net evidence. How many samples the decision maker collects will depend on his/her cost of time and benefit from making the right choice. **(g)** A sequential sampling model (SSM) representation of how this net evidence is accumulated up to either a low threshold (as in (e)) or a high threshold (as in (f)). Once the decision variable reaches a predefined threshold, the decision maker stops collecting evidence and makes a decision. Higher thresholds require more time but lead to more accurate responses, as seen in **(h)**. Here we again see two choice curves for A over B, one (in blue) resulting from a high threshold, and one (dashed in red) resulting from a low threshold.