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Cognitive science contributions to decision science

Jerome R. Busemeyer

Psychological and Brain Sciences, Indiana University, 1101 E. 10th St., Bloomington, IN 48705, United States

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ABSTRACT

This article briefly reviews the history and interplay between decision theory, behavioral decision-making research, and cognitive psychology. The review reveals the increasingly important impact that psychology and cognitive science have on decision science. One of the main contributions of cognitive science to decision science is the development of dynamic models that describe the cognitive processes that underlay the evolution of preferences during deliberation phase of making a decision.

1. Introduction

Is cognitive science having an impact on decision science, and if so, when did this happen, and what is this impact? The answers are yes, and recently, and it is the ability to describe the dynamical nature of the decision-making process. However, to understand the answers to these questions, we need to look back into the history of decision research and see exactly where cognitive science really enters the picture in an important and unique way.

2. Economic influence on decision science

Decision science is a very large field comprised of researchers from economics, engineering, marketing, statistics, philosophy, psychology, and finally, cognitive science. Decision science has a very long and venerable history going back as far as the 17th and 18th century with initial theoretical formulations by Pascal (1671/1950), Cramer in 1728, and Bernoulli (1738/1954) and others. Arguably the most important and influential contribution in decision science was the axiomatic formulation of expected utility (EU) theory for decisions under risk in the 1940s by Von Neumann and Morgenstern (1947/1970), and the later extension to subjective expected utility for decisions under uncertainty by Savage (1954).

The axioms of EU theory are a small (3 or 4 depending on the version) set of behavioral properties that a decision maker is supposed to obey. For example, one axiom is dominance – if action A is at least as good or better than action B under all states, then action A should be chosen. Another axiom is transitivity – if action A is chosen over B, and action B over C, then action A should be chosen over C. A third axiom is independence – if two actions involve the same consequence under a given state, then this common consequence should not matter. These axioms strike many decision scientists as intuitively compelling and the rational way to make decisions. Therefore, these behavioral axioms form the definition of rational decision-making: a rational decision maker is a person who obeys the axioms of EU theory.

The way to guarantee obedience to these axioms is by using the EU formula to make choices, which is actually a *theorem* derived from the axioms. The EU formula assigns a utility to each action, by computing a probability-weighted average of the utilities of outcomes produced by an action. The rational decision maker chooses the action with the maximum EU. By using this rule, one is guaranteed to obey the axioms. Furthermore, for anyone who obeys the axioms, their behavior can be *reproduced* by this formula, that is, their behavior can be described "as if" they used the EU formula. Using Marr's (1982) levels of analysis, the EU formula is the computational goal of the rational decision maker. According to EU theory, decision-making boils

E-mail address: jbusemey@indiana.edu

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down to the use of only two central concepts: the probability *weight* and the utility *value* that a decision maker assigns to each outcome.

Economists and business researchers working in decision sciences adopted EU theory wholeheartedly, greatly expanding this axiomatic foundation, and delving into deep and important applications using this theory. Economic theories and applications usually begin with the assumption that all agents are rational, that is they are all EU maximizers. However, informal surveys in the 1960s by behavioral economists, such as Allais (1953) and Ellsberg (1961), and subsequent experiments in the 1970s by psychologists such as Kahneman and Tversky (1979) provided convincing evidence that people systematically violate one of the axioms of EU theory – the independence axiom. This prompted some decision scientists, such as for example Machina (1987) and Wakker (2010), to question the applicability, and even the rationality, of the independence axiom. New and more general axiomatic formulations of utility theory were developed, such as those used in rank dependent utility (RDU) theory, proposed by economists such as Quiggin (1982) and Schmeidler (1989). (It is worth noting that these ideas were anticipated by psychologists, Birnbaum and Stegner (1979), Lopes (1987) and Luce (2000).) Although this seems like a revolution in decision theory, the basic ideas did not change: decision-making still boiled down to the use of two concepts: weights and values (but now in more general forms).

3. Psychological influence on decision science

The psychological study of behavioral decision making started in the early 1950s, initiated by psychologists such as Coombs (1964), Edwards (1954) and Peterson and Beach (1967). They introduced the simple gambling paradigm, that is, giving people choices among pairs of simple gambles. They initiated a program of research to explore the hypothesis that "man was an intuitive statistician." In other words, this research designed to experimentally determine how well the EU rule could in fact predict human decision-making behavior. This early work claimed some limited success in the sense that the EU rule turned out to be a fairly robust first approximation to human decision-making.

Soon afterwards, the "man is an intuitive statistician" program of research radically changed direction under the influence of Tversky and Kahneman (1974). The revised program was now aimed at showing that in fact people systematically violate the axioms of rational decision theory in fundamental ways. Kahneman and Tversky (1979) were very effective at demonstrating various types of violations, including common consequence, common ratio, and reference point effects. Their work culminated in the formulation of a more descriptively accurate (as opposed to strictly rational) theory of decision making called *prospect theory*. Prospect theory is essentially a relaxed version of EU theory that builds in some psychological features such as non-additive probability weights and the introduction of loss aversion into the utility function. However, once again, decision-making boiled down to the use of only two concepts: weights and values (but now more psychologically descriptive).

The failure of EU theory prompted other psychologists to look for completely different rules that were simpler, less optimal, and not strictly rational. This lead to the exploration of toolboxes of simple *heuristics* as originally suggested by Simon, Augier, and March (2004) in the 1950s, and Kahneman and Tversky in the 1980s, and this idea was pursued more programmatically in the 1990s and 2000s by psychologists such as Payne, Bettman, and Johnson (1988) and Gigerenzer and Todd (1999). For example, within a decision environment that is *appropriate* for the tool, a simple rule such as the lexicographic rule, also known as the "take the best rule," produces decisions that come close to matching an optimal rule, but with much less cognitive effort. The lexicographic rule evaluates options one attribute at a time, starting with the most important, and working down to less important attributes. If one action exceeds all others on the most important attribute, then it is immediately chosen without considering other attributes; if several actions are approximately equal on the first attribute, then the second attribute is evaluated, and so on. Referring again to Marr's levels of analysis, heuristic toolbox models attempt to understand the simple algorithms people use to achieve their computational goals. The development of toolboxes of heuristics is perhaps the first fundamentally psychological contribution to decision science. These rules have been implemented within cognitive production rule systems such as the Adaptive Control of Thought (ACT-R) model (Anderson & Lebiere, 1998). The "tool box of heuristics" approach is one that clearly departs from the basic weighted average rule of EU theory, and it is one in which decision-making is based cognitive principles of limited information processing that go beyond the two concepts of weights and values.

Heuristic decision rules, such as the lexicographic rule, represent a very drastic departure from the EU rule. The EU rule is compensatory in nature – disadvantages along one dimension (possibility of loss) can be compensated by advantages along another (high possibility of a large gain). Heuristics, such as the lexicographic rule, are usually non-compensatory in nature, e.g., if the options differ on the first dimension that is evaluated, then later dimensions are not evaluated at all, no matter how good or bad! This can lead to violations of dominance and transitivity, which many decision scientists consider to be unacceptable "irrational" properties of a decision theory.

4. Cognitive science influence on decision science

Starting in the 1950s, cognitive scientists were busy developing their own theories of decision making for cognitive tasks such as perception, memory recognition, and categorization. The earliest and most prominent was the signal detection model promoted by Green and Swets (1966). The purpose of signal detection theory was to describe how decision makers make inferences about an uncertain state of nature based on a noisy sample of state information (e.g., decide whether an X-ray image is sampled from a patient that has a benign or cancerous tumor). The model