BBS-D-12-00821_Corr_Pothos & Busemeyer

<CT>Cold and hot cognition: Quantum probability theory and realistic psychological modeling

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<C-AB>**Abstract:** Typically, human decision making is emotionally "hot" and does not conform to "cold" classical probability (CP) theory. As quantum probability (QP) theory emphasises order, context, superimposition states, and nonlinear dynamic effects, one of its major strengths may be its power to unify formal modeling and realistic psychological theory (e.g., information uncertainty, anxiety, and indecision, as seen in the Prisoner's Dilemma).

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Classical probability (CP) theory has struggled to provide a comprehensive, sometimes even adequate, description and explanation of human decision making. This conclusion has pervaded psychology and related disciplines, for example in economics, where the notion of a rational single-type *homo economicus* is fast falling out of favour and being replaced by one that highlights the heterogeneity of economic agents and their decision-making processes. Many behavioural scientists doubt that formal modeling based on CP principles can describe and explain even relatively simple laboratory-based behaviour, let alone the everyday examples that, typically, entail some degree of emotional activation by virtue of the different payoffs associated with different possible outcomes. The fact that different outcomes exist is, itself, sufficient to induce conflict-related emotion, thus rending typical human decision making "hot."

Whatever the ultimate value of quantum probability (QP) theory, it represents a promising way forward to model the computations of cognition involved in complex psychological situations. The need for such a formal modeling theory is highlighted by the trend in recent years towards an integration of "cold" cognition with "hot" (emotional) processes and decision making, as seen in the "cognition-emotion" literature. CP theory is poorly equipped to meet this challenge. This commentary explores the potential of QP theory to provide a general modeling approach for realistic psychology theory.

In the typical laboratory situation, the experimenter tries to control all extraneous variables to isolate only those of interest; however, in the case of human studies, internal states of the participant cannot be controlled. Participants bring to the experimental situation their own expectations, desires, and habitual modes of thinking and behaving; and, worse still for the experimentalist, these factors differ among individuals. This fact is seen readily in experimental games studied by behavioural economists, in which understanding of behaviour is impoverished by failing to account for dispositional differences in preferences and personality (Ferguson et al. 2011).

The abovementioned points can easily be illustrated in relation to the "sure thing" principle seen with the prisoner's dilemma problem. The literature shows: (1) knowing that one's partner has defected leads to a higher probability of defection; (2) knowing that one's partner has cooperated also leads to a higher probability of defection; and, most troubling for CP theory, (3) not knowing one's partner's decision leads to a higher probability of cooperation. Everyday equivalents of this situation do not, typically, resemble the decision-making dynamics assumed by CP theory: people have *psychological* processes that it fails to model, or to even consider to be relevant. For example, in this situation, outcome (1) could simply be (self-serving) retaliation; and in the case of (2) taking the easier route, but, we should wonder, what would happen if the partner was a loved one (e.g., your child)? Scenario (3) is a situation of uncertainty and psychological conflict (at least as perceived by many participants), and we know from the literature that such conflicts lead to cautious, risk-assessing behaviour which should be expected to lower rates of defection (which represents a final decision devoid of any cognitive dithering). Not knowing one's partner's decision is, in psychological if not logical terms, very different to outcomes (1) and (2); therefore, we should expect a different decision outcome.

The main point of the previous discussion is that in a situation of information uncertainty, people's decisions will be influenced by a host of factors, including evaluation of likely payoffs as well as consideration of reputational damage and likely carry-over effects to other situations. Most decision situations outside the laboratory do not resemble the constraints of the one-shot experiment, and in this situation people find it difficult to break free from their habitual forms of cognition. In actual fact, most laboratory-based decision-making situations are not as tightly constrained as assumed by the experimenter; for example, the experimenter typically knows the participant's decision and the participants know that the experimenter knows. This is relevant information from the participant's point of view. In designing experimental situations, it is important to make things as simple as possible, but not to the extent that the situation loses touch with psychological reality and, therefore, external validity.

As an example of the consequences of information uncertainty, which is inherent in the prisoner's dilemma problem, psychological entropy has been used to account for its effects. As noted by Hirsh et al. (2012), "As a system's disorder and uncertainty increases, its ability to perform useful work is hampered by reduced accuracy in specifying the current state, the desired state, and the appropriate response for transforming the former into the later" (p. 305). They further note that uncertainty leads to goal-conflict and anxiety, which adds further emotional heat to the cognitive system. And, as with many other processes, in the specific example of conflict-related anxiety, we observe a change in the balance between controlled-reflective and automatic-reflexive behaviour (Corr 2011) which can, and often does, lead to nonlinear dynamic effects of the type predicted by QP theory. In addition, the perception of potential rewards and punishments in the situation trigger prepotent automatic reactions (e.g., in the case of goal-conflict anxiety, behavioural inhibition and cognitive rumination; McNaughton & Corr 2004) which we may well expect to impact on decision-making processes in complex, but unpredictable, ways. Therefore, CP modeling of the prisoner's dilemma problem does not tell us much about how people actually behave in "hot" decision-making situations.

In contrast, one major opportunity of QP theory is the provision of a general computational framework for the modeling of dynamic, and realistic, psychological processes. As Pothos and Busemeyer observe, QP theory has strong potential in this regard because it takes account of processes that are strongly order and context dependent, recognises that individual states are often superimposition states, and assumes that composite systems are often entangled and cannot be composed into their separate subsystems. It would be valuable for Pothos and Busemeyer to consider how their proposals for QP theory might be extended to start to address emotionally hot cognition and behaviour.

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<RFT>References**[**Philip J. Corr][PJC]

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