Journal of Economic Psychology 41 (2014) 45–54

Contents lists available at SciVerse ScienceDirect

Journal of Economic Psychology

journal homepage: www.elsevier.com/locate/joep

Dual-process theories of decision-making: A selective survey ☆

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ARTICLE INFO

Article history:
Received 28 March 2012
Received in revised form 9 January 2013
Accepted 18 January 2013
Available online 29 January 2013

JEL classification:
D87

PsycINFO classification:
2340

Keywords:
Neuroeconomic theory
Decision-making
Dual-process
Constrained optimization

ABSTRACT

Brain modularity is a key concept in neuroscience. It challenges the common view of the single coherent self adopted in many disciplines, including economics. Multi-process theories of decision-making rely on the existence of several brain systems interacting with each other to revisit standard paradigms of choice, propose choices that fit the behavioral data better, and offer testable predictions. In this paper, we present a selective review of our recent research in this area. We focus on constrained optimization models rather than the computational models extensively used in neuroscience.

1. Introduction

1.1. Brain modularity and neuroeconomic theory

The premise of neuroeconomic theory is the existence of multiple interacting brain systems. The relationship between brain systems is intricate. Typically, each system performs different functions and each function needs the intervention of several systems. Neuroscientists refer to it as *brain modularity*. Taking a decision, solving a problem or performing a motor task requires the coordination of different functions and therefore the involvement of different systems. Depending on the nature of the function and the degree of the overlap between systems, they will produce a response that is 'as if' they were cooperating with each other or 'as if' they were competing with each other.

The main consequence of such a construct is that an individual is best understood as an *organization of systems*. When a choice must be made, systems performing functions related to that decision are recruited. Those systems independently or jointly contribute to the decision. The final outcome emerges from a complex process and may not be consistent with predictions made by standard economic models of decision-making. Indeed, traditional models presuppose that the individual is a single coherent entity with well defined underlying preferences, a clear understanding of the environment, and an unparalleled ability to learn. Such a normative view is extremely useful because it defines a benchmark for comparison with

☆ For more information on our "neuroeconomic theory" project, visit the website of our laboratory TREND at http://www.neuroeconomictheory.org.

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0167-4870/$ - see front matter
http://dx.doi.org/10.1016/j.joep.2013.01.004

actual behavior. However, it overly simplifies decision-making and, as a result, does not always represent well the observed behavior.

The idea that standard models do not always represent actual behavior accurately is not new. Researchers in the fields of "bounded rationality" or "behavioral economics" have developed behavioral models that fit data better. Some of these models rely on the intuition that decision-making is not made by a unique coherent entity. Inter-temporal choice offers a good example. For some authors, an individual is best understood as a succession of selves with different preferences and different levels of awareness of such preferences. Hyperbolic discounting is one such model (see e.g., Strotz (1956); Laibson (1997); O'Donoghue & Rabin (1999) and Carrillo & Mariotti (2000)). It explains, in particular, why decision makers prefer a small reward today to a big reward tomorrow and, at the same time, a big reward in 1 year and 1 day to a small reward in 1 year. Still, this type of model is built to account for observed behaviors. As such, the set of variants is large, making it sometimes difficult to determine which assumptions are the most appropriate. A related strand considers the individual as an entity with conflicting objectives. In the next section we briefly review some papers in this "dual-process" approach to decision-making, a well-established branch of the literature which is the central topic of this special issue (we refer to Rustichini (2008) for a critical review of the unitary vs. dual system approach and to Livnat & Pippenger (2006) and Bisin & Iantchev (2010) for evolutionary arguments in favor of duality).

1.2. Dual-process models of decision-making

The earliest accounts of dual-process theories in psychology date back to Schneider and Shiffrin (1977a) and Schneider and Shiffrin (1977b) who used a series of experiments on attention to propose a theory of information processing based on two processing modes: *controlled and automatic*. This type of models has been extended and applied to economic situations. Bernheim and Rangel (2004) study consumption under the assumption that the individual operates either under a 'cold mode' where he selects his preferred alternative or a 'hot mode' where choices may be suboptimal given his preferences, and show that the model accounts for a number of patterns well documented in the addiction literature. Benhabib and Bisin (2004) show that an agent with the ability to invoke either an automatic process susceptible to temptation or a costly but non-tempting control process will follow a simple consumption–savings plan characterized by a cut-off rule for invoking the control process. Loewenstein and O'Donoghue (2005) use this duality to explain, among other things, why people tend to exhibit an S-shaped probability-weighting function.

In another set of models pioneered by Thaler and Shefrin (1981) and Shefrin and Thaler (1988), dual-processes take a *myopic vs. forward-looking* temporal dimension: the individual is split into a long term planner interested in the future effects of choices and a short-sighted doer interested in immediate gratification only. The authors use the model to explain the benefits of commitment devices such as mandatory pension plans and lump-sum bonuses in promoting savings. They have been extended and further developed by Fudenberg and Levine (2006) and Fudenberg and Levine (2011). The first paper argues that the split-self approach with linear cost of self-control can explain dynamic preference reversals and the paradox of risk-aversion in the large and in the small whereas the second paper can explain the Allais paradox provided that the cost of self-control is convex.

Naturally, such duality may take other forms. For example, in the self-signalling game of Bodner and Prelec (2003) and Mijovic-Prelec and Prelec (2010) one mechanism selects an action and another mechanism interprets the action selected or, more precisely, draws inferences from the action and generates emotional responses consistent with those inferences.

However, and with few notable exceptions (e.g., Bernheim & Rangel (2004)), the multiple-process models are mostly loosely inspired by biological processes. Given the current knowledge from neuroscience and neurobiology, we believe that it is now possible to build models grounded more directly on the evidence provided by those disciplines. In other words, the multiplicity of systems should not be used as a tool to fit empirical facts but it should rather try to accurately represent the way information is processed and decisions are made in the brain. In this article, we present a selective survey of some of our recent research. We put a special emphasis on examining how modeling the actual processes that lead to choices can illuminate our understanding of economic behavior. The survey is obviously partial and incomplete, with many important contributions to neuroeconomics not being discussed. Our goal is to provide some examples of what a multi-process constrained optimization methodology has to offer to understand individual decision-making. We refer the reader to the original papers for the formal proofs of the results and for an exhaustive review of the literature related to those papers.[1] Before discussing the models, we provide in Section 2 a brief description of the methodology we use to map information about neural activity into models of the brain (see also Brocas & Carrillo (2008a)).

2. Building 'as if' models

The methodology used in neuroeconomic theory is in fact quite close to the methodology economists rely onto represent the choices of an individual assuming he is a coherent entity. We are simply taking one step back: the coherent unit is not the individual but rather the cells (and perhaps the systems) that compose him.

[1] A more exhaustive survey of recent advances in neuroeconomics can be found in Fehr and Rangel (2011), although it focuses mainly on computational models and experimental results and barely mentions dual-process models. Other important contributions left out of the review include for example the axiomatic model of dopaminergic function developed by Caplin and Dean (2008) and tested by Caplin, Dean, Glimcher, and Routledge (2010).