Erasmus Journal for Philosophy and Economics,
Volume 4, Issue 1,
Spring 2011, pp. 88-94.
http://ejpe.org/pdf/4-1-br-2.pdf

Neuroeconomic reductionism at work? A review of Paul W. Glimcher's *Foundations of neuroeconomic analysis*. New York: Oxford University Press, 2011, 488 pp.

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Recent years have seen a wave of interest in connections between neuroscience and the models and generalizations of neoclassical and behavioral economics. Interdisciplinary investigations of decision-making in humans and non-human animals have yielded a flagship neuroeconomics textbook (Glimcher, et al. 2009), hundreds of journal articles, and high-profile academic conferences. They have also attracted constructive and destructive criticism—not to mention charges of hype and irrelevance—from cognitive neuroscientists (Gallistel 2009), economists (Gul and Pessendorfer 2008), and philosophers of science (Ross 2008).

Paul Glimcher is one of the most creative, interdisciplinary, and philosophically inclined neuroscientists currently working on decision making. His book *Decisions, uncertainty, and the brain* (2003) put his research on primate visual decision-making in the context of a brief history of neuroscience since Descartes's work on the reflex and even included a short discussion of consciousness and philosophical zombies. Glimcher's latest, cheekily titled *Foundations of neuroeconomic analysis* (hereafter *FNA*) presents the case for his laboratory's research program seeking no less than a "partial reduction […] of economics to psychology and thence to neuroscience" (Glimcher 2011, xv).

FNA is organized into four main sections, the first of which tackles the difficult issues of inter-theoretic relations and reductionism. Here, Glimcher partially traces the history of the idea that all scientific theories may be reducible to fundamental physical theory from the logical positivists through Ernest Nagel, briefly discussing critiques from C. D. Broad, Jerry Fodor, and others along the way. Nothing he says here will be new to philosophers of science, and unfortunately there is no discussion of more recent work on reductionism from philosophers of biology or the social sciences (for a review of these issues, see Sarkar and Wimsatt 2006). To cite one example, William Wimsatt's (2007) discussion of the "functional localization fallacy"—mistakenly attributing a property of a whole system to a functionally important part of that system—may turn out to be relevant to attempts at neuroeconomic reduction. In general, Glimcher seems unaware of the bewildering variety of ways in which reduction is construed, in terms of theories, models, entities, explanations, methodologies, and so forth. Indeed, some philosophers have gone so far as to suggest that talk of reduction should simply be eliminated in favor of more precise terminology (Maclaurin 2011).

Here the crucial question for Glimcher turns out to be whether mathematically explicit theories from economics may be mapped onto those from neurobiology homomorphically, that is, preserving their mathematical or logical structure. It is well known that this cannot be taken as a plausible account of reduction in general, as a homomorphic mapping between two mathematical models need not imply inter-theoretic or intra-theoretic reduction (Schaffner 1967). For example, a single well-known set of differential equations models phenomena in epidemiology and certain predator-prey systems. While this may be biologically suggestive, it need not imply a reduction. Homomorphism between models could be taken as merely a necessary condition on successful reduction, or one might opt for a stronger condition like isomorphism, an idea originally suggested by Suppes (1957) that has long since been challenged (Sarkar 1992).

Philosophical problems aside, on this issue Glimcher is careful to hedge his bets, claiming that while "there almost certainly will be regularities that homomorphically map some economic kinds to neurobiological kinds" (p. 31), we should not expect such attempts to proceed without exceptions (genuinely emergent properties) or without *modifying* existing higher and lower-level theories as we go. What really matters is producing more predictive, more explanatory theories, and the history of inter-theoretic reductionism, in biochemistry for example (pp. 26-28), gives us empirical grounds to conclude that his explicitly reductionist research program will bear fruit whether or not strict reductions of the logical objects of *current* economic theory to *current* neurobiology are in the offing. Thus in practice, 'partial reduction' just means 'interdisciplinary synthesis'. He has already argued persuasively in his earlier work that ideas from economics can help structure our theories about what the brain does—here a higherlevel theory swoops in to save a lower-level theory from absurdity (Glimcher 2003).

The remainder of the first section of *FNA* is devoted to laying out for non-specialists the theories to be connected to neurobiology: neoclassical economic theory, the psychophysics of perception (particularly signal detection theory), and the famous “anomalies” of expected utility theory (Allais’s and Ellsberg’s results, the endowment effect, and risk-seeking over losses). Glimcher’s interdisciplinary sweep serves three purposes. The first, just mentioned, is to provide compact summaries of disparate fields for non-specialists. Whether he succeeds here is not for me to say, but I suspect readers will appreciate his clear explanations and examples. It is also worth noting in this context that each chapter of *FNA* contains a helpful précis that often advises practitioners of a particular discipline to skip ahead (most readers of this journal will probably not need to be reminded of the von Neumann-Morgenstern axioms of expected utility theory).

The second goal is to provide a kind of preview of his strategy of reductionistic linkage. He does this by suggesting how the psychophysics of perception could be connected to random utility models of economic theory. The idea is that a noisy perceptual intensity curve mapping, say, concentration of sugar in solution to perceived sweetness, could be connected to a noisy or random utility curve (McFadden 1974) describing choices of hungry subjects between solutions with these sugar concentrations (Glimcher 2011, 93-98) —random utilities turn out to be quite important for Glimcher: he stresses the fact that the brain is a stochastic organ, so some of its processes cannot be accurately modeled by deterministic algorithms (chapters 9 and 10).

The third goal of section one is to motivate a rejection of the instrumentalist-behaviorist tradition in economics, the insistence that economic theories are only as good as their predictions about choice behavior (Friedman 1953; Gul and Pessendorfer 2008). On this view, whether individuals or firms actually compute expected utilities, consciously or unconsciously, is irrelevant to testing expected utility theory. What matters is that they choose *as if* they performed such computations. Glimcher calls such *as-if* theories “Soft theories” and proposes instead that we consider *because* theories or “Hard” economic theories that predict that the relevant computations *are* being performed somewhere in the brain. There is no knockdown argument against the diehard instrumentalist, however: "We can make mechanistic test irrelevant by assertion […] but that is a political rather than a scientific operation" (Glimcher 2011, 132). Rather, the only way to convince the *as if* theorist is to produce successful *because* theories.

The rest of *FNA* is an extended argument that successful *because* theories are possible, so neuroeconomic reductionism is a viable research strategy. The second and third sections concern the neural mechanisms of choice and valuation, respectively. Those interested in Glimcher's neuroscientific work would do well to skip immediately to these sections and read them carefully. In summary, Glimcher argues that our brain contains networks for valuation, mediated by midbrain dopaminergic neurons that allow us to learn the subjective value of behaviors, which feed to choice networks in the prefrontal and parietal regions, which in turn feed to motor output.

In the fronto-parietal choice network, topographically organized neurons encode, by their mean firing rates, the "relative expected subjective value" of particular motor actions (p. 242), for example moving the eyes towards a particular target. The valuation circuit feeds the cortical choice network these value-signals over actions, which are (somehow) normalized over choice sets (pp. 236-250). The valuation signal and the choice network itself have some degree of stochasticity, which can apparently be modulated by adjacent cortical neurons. Thus choice may appear more or less random, depending on contextual factors, for example the size of the choice set (pp. 246-247).

Choice occurs when firing rates exceed a certain threshold, which apparently may happen in one of two ways: either a "winner-take-all" computation is performed and the action with the highest associated firing rate is performed, or else a "reservation price" is (somehow) set by the network, and the first action whose firing rate exceeds the threshold is performed. Glimcher argues that these correspond to the "arg-max" operation of expected utility theory and the satisficing, reservation-price-based algorithms due to Simon (1955), respectively. Lingering empirical difficulties include whether the model, based mostly on studies of visual decision-making in monkeys, can be generalized to more complicated behaviors and actions, how cortical normalization occurs, and why and under what conditions the two different kinds of computations leading to choice behavior are performed.

The third section of *FNA* deals with the valuation network, where again Glimcher seeks an interdisciplinary synthesis of contemporary neuroscience with models from psychology, computational learning theory, and economics. Here Glimcher introduces temporal difference models of reinforcement learning, and he reviews evidence that these are implemented by midbrain dopaminergic neurons, particularly in the ventral striatum (chapter 13). The basic idea behind these models is that an organism learns the value of an action by predicting its expected value and then using the difference between experienced reward and the prediction (the reward prediction error) to update their expected value prediction. Recently, Caplin and Dean (2007) axiomatized reward prediction error systems and Glimcher and his colleagues found that activation patterns in the striatum follow these axioms—a major success for the neuroeconomic research program.

Activation patterns in the medial prefrontal cortex have also been correlated with subjective valuation and preference, relative to a baseline or reference-point (Glimcher 2011, 349). Upward shifts relative to the baseline firing rate (representing *gains*) have been shown to be less than downward shifts (representing *losses*), the degree of asymmetry predicted by standard behavioral measures of loss aversion. Glimcher argues that the data suggest a neural implementation of Kozegi and Rabin's (2006) models of reference-dependent preferences. The remainder of the section on valuation reviews what little else we know about how subjective values are constructed and stored, including uncertain roles for the amygdala, insula, dorsolateral prefrontal cortex, and orbitofrontal cortex. This is the most speculative section of the book: we know very little about how all of these parts of the brain work together to construct and store a subjective value signal.

There is no doubt that Glimcher has succeeded in providing, at the very least, an outline of a causal-mechanistic microfoundation for microeconomics. While it may be a difficult read at times, fans and skeptics alike will profit from carefully absorbing *FNA*. Glimcher has revived Bentham's view that "utiles" may someday be identified in the brain. However, difficult questions remain. How is the subjective value signal generated and stored? Can Glimcher's simple model of choice be extended to complex behaviors and tasks? How much of our economic agency is located *outside* of the head in the environment and our technologies? What about the role of language and symbolic thinking? Which individual and social properties will be resistant to relentless neuroeconomic reductionism? If neuroeconomic research outlives the hype and overblown criticism, hopefully we will get some answers.

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