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Using neuroeconomics to understand environmental valuation

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A R T I C L E I N F O

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A B S T R A C T

Contingent valuation, choice experiments, and other stated preference methods are frequently used to capture the nonmarket valuation of natural resources and ecosystem services. The emerging field of neuroeconomics, which assesses the neuroscience underlying decision-making, plots a promising course to explore the mechanisms underlying complex environmental valuation decisions. Neuroeconomic methods offer a unique capacity to isolate value components that contribute to willingness-to-pay (WTP), separating an individual's response to natural resource attributes that are of interest to economists from other attributes or influences on the decision process. Neuroimaging data can also aid in understanding differences in response between preference elicitation techniques and identifying the use of different decision processes and heuristics during valuation. This article surveys the benefits and limitations of using neuroeconomics methods to assess the value of environmental goods, and focuses on three examples where neuroeconomics may inform environmental valuation: protest responses, comparison of hypothetical and consequential choice contexts, and the evaluation of environmental attributes and optimization of study design in stated choice experiments. Neuroeconomics methods offer a foundation for positive collaboration between environmental economists and cognitive neuroscientists, yielding metrics that complement and augment current stated preference methods of determining environmental valuation.

1. Background

In an effort to capture consumer preferences for environmental goods and services which are not historically assigned market values, stated preference valuation techniques have emerged that elicit individuals' willingness-to-pay (WTP) for natural resources. These approaches can provide an estimate of the total economic value of an environmental good, including the utility that individuals derive from the continued existence of natural resources they may never encounter (Arrow et al., 1993). Such intangible benefits can be difficult to estimate with revealed preference techniques (Navrud and Pruckner, 1997). While contingent valuation (CV) surveys have historically been one of the most prevalent stated preference methods, multi-attribute choice experiments have also become increasingly common (Adamowicz et al., 2014). Across these approaches, discussions have debated the best ways to elicit true preferences and counteract methodological vulnerabilities (Carson, 2012; Haab et al., 2013; Hausman, 2012; Kling et al., 2012) and stated the case for further empirical and behavioral research to resolve open questions on issues like hypothetical bias (Haab et al., 2013) and the cognitive burden of complex discrete choice tasks (Louviere et al., 2011).

The field of neuroeconomics has had recent success in improving the understanding of heuristics and systematic biases during financial decision-making by using neuroimaging methods (primarily functional magnetic resonance imaging, or FMRI) during behavioral economics experiments (Genevsky and Knutson, 2015; Kable and Glimcher, 2007; Knutson et al., 2007; McClure, 2004; Tong et al., 2016). Neuroeconomic methods may show similar promise when applied to environmental valuation. Uniquely, neuroimaging experimental designs allow researchers to separate attributes of both the item or choice being evaluated (Ballard and Knutson, 2009; Karmarkar et al., 2015) as well as distinct phases of the decision-making process (Hare et al., 2010; Knutson et al., 2007), deconstructing the neural responses to each, allowing deeper examination of multi-attribute choice experiments and identifying potential confounds. Moreover, neuroimaging designs have examined and quantified the functional differences in hypothetical versus incentive-compatible decision-making (Kang and Camerer, 2013; Kang et al., 2011) and other contexts of concern to environmental valuation.

This article aims to address how neuroeconomics might inform environmental valuation by first introducing the benefits and limitations of neuroeconomic methods, and then highlighting several examples of how these methods can investigate issues of interest to stated preference researchers: protest bids, hypothetical choice and consequentiality, and the multi-attribute nature of stated choice experiments. Lastly, a walkthrough of an existing environmental valuation experiment

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using neuroimaging (Sawe and Knutson, 2015) will offer a concrete example of the ways in which such interdisciplinary work can be designed and analyzed, with cautious interpretation of early results, and discussion of opportunities for future research.

2. An Introduction to Neuroeconomics: Advantages and Limitations

Neuroimaging studies have been particularly instructive in elaborating the affective (emotional) influences that foster "irrational" but well-documented biases during choice, such as the endowment effect (Knutson et al., 2008) and loss aversion (Tom et al., 2007). Neuroeconomic methods can quantify, explain, and even predict components that contribute to people's frequent departures from the choices of an economically rational actor. Since affective responses and moral considerations can influence stated preference WTP measures (Diamond and Hausman, 1994; Kahneman et al., 1999), compromising their usefulness to economists (e.g., fueling protest responses) and revealing systematic inconsistencies in the way people value natural resources (Diamond and Hausman, 1994), neuroimaging seems ideally suited to examine protest bids and other problematic valuation responses. Neuroimaging allows the separation of positive and negative affective influences on the decision process from signals related to the computation of subjective value and the performance of cost-benefit assessment (Knutson and Greer, 2008), owing to distinctly identified neural regions of interest for each. This can isolate signals related to an individual's valuation of different attributes of a natural resource from emotional or moral inputs that may either strengthen or bias integrated value assessment. In this framework, the rational actor is only one of several internal influences on the value estimates of environmental goods. Neuroimaging affords the capacity to examine both the extent and timing of these different influences.

The benefits of neuroeconomic applications to environmental valuation are not limited to explanatory mechanisms, since they also facilitate the modeling and prediction of behavior (Knutson et al., 2007). This capacity for prediction can extend beyond study samples to the general population. In real-world choice paradigms as diverse as food and music sales (Berns and Moore, 2011; Kühn et al., 2016), advertisements (Venkatraman et al., 2015), the efficacy of anti-smoking ad campaigns (Falk et al., 2012), and the success of microloan requests (Genevsky and Knutson, 2015), neural data has successfully forecasted population-level behavior. Moreover, the neural data can sometimes outperform study participants' own self-reported ratings (e.g., how much they liked a song) and actual decisions (e.g., microloan offers) in its ability to forecast population-level behavior (Berns and Moore, 2011; Falk et al., 2012; Genevsky and Knutson, 2015).

To understand how a mismatch between a signal in the brain and the subsequent behavior could occur at the individual level, reflect on your taste in music for a moment. You may find the hook of a song catchy, but your rating of it would incorporate a number of other evaluative elements: your views on the genre, what friends would think of the song, and so forth. Individual decisions often involve multiple attributes, and individual differences in attribute-specific preferences might thus generate differences in final reported valuations and choices. But at the population scale, neural response in a specific circuit can become a common predictor of choice across individuals, successfully circumnavigating complexities that can complicate self-report. In the case of valuation of natural resources and ecosystem services, where self-report measures may be criticized for unreliability, it is crucial to explore new methods which can reliably predict choice, preference, and value in other decision contexts.

Though neuroeconomic research utilizes a range of techniques to illuminate the roles of brain circuits in decision-making, including electroencephalography (EEG) and transcranial magnetic stimulation (TMS), a number of prominent studies on affective contributions to decision-making have utilized functional magnetic resonance imaging (FMRI) (Knutson et al., 2001, 2007; Mayr et al., 2009), including most of the studies which have successfully forecasted population-level behavior using brain data (Berns and Moore, 2011; Falk et al., 2012, 2015; Genevsky and Knutson, 2015; Kühn et al., 2016; Venkatraman et al., 2015). The prevalence of FMRI stems from the method's advantage in balancing trade-offs between spatial (on the order of millimeters) and temporal (on the order of seconds) resolution when observing neural activity (Cohen, 2005). Based on available findings, this discussion will focus on methodology and experimental research using FMRI, similar to other discussions of the interdisciplinary applications of neuroscience techniques (e.g., education, Varma et al., 2008).

2.1. Time and Space in Experimental Design

Neuroimaging with FMRI tracks brain activity through localized changes in cerebral blood flow. Due to the considerable metabolic demands of firing neurons, a surplus of oxygenated blood rushes to active brain regions within seconds of their initial recruitment. By looking at BOLD (Blood Oxygenation Level-Dependent) signals over time (or "activity") as subjects make decisions, neural circuits which activate during and even prior to choice can be localized. Optogenetic research confirms that the BOLD signal provides an approximate index of neural activity (Lee et al., 2010), but the BOLD signal occurs more diffusely and on a slower timescale than neural activity, limiting FMRI data to a temporal resolution of seconds and a spatial resolution on the order of millimeters (Cohen, 2005).

Though this resolution still captures a wealth of structural information relevant to psychological processes, the spatial and temporal constraints of the BOLD signal have implications for experimental design. For example, extremely fast but functionally relevant activity may escape detection, especially when small or brief signals are averaged across longer timescales. The timing and presentation of stimuli must also be strictly controlled in order to interpret neural activity in response to each of the separate components of a decision process. For instance, deriving meaningful inferences about the neural activity of an individual who is freely reading two long paragraphs which differ in some way would prove challenging (even though this is a typical presentation format for CV stimuli). Since each person's reading speed differs, the point at which they encounter the variable of interest would be unclear, and averaging the signal over the long timescale necessary for reading might "wash out" increased activity in response to the variable of interest. Thus, researchers often design FMRI tasks by breaking down and splicing the information into discrete portions (e.g., each 2–8 s in length), which permits visualization of distinct neural responses to specific components of the decision process (for an example, see Fig. 1).

Separating each variable of interest across time allows researchers to visualize changes in neural activity in response to differences within a variable. For example, Fig. 1 depicts a trial designed to test affective valuation of threatened natural resources. This design allows for systematic variation of the attractiveness of threatened resources, the destructiveness of proposed land uses, and the amount requested to offset the damage (Sawe and Knutson, 2015). This enabled later analysis of how activity in relevant brain circuits changed in response to aspects such as differing proposed land uses which were perceived as more or less destructive to the parks. This study will be explored in further detail below, as the findings offer insights into affective influences on environmental valuation.

2.2. Repeatability and Incentive Compatibility

In another tradeoff, FMRI activity often includes substantial noise components. Conditions are repeated dozens of times within-subject in order to improve the signal-to-noise ratio (Huettel and McCarthy, 2001). Fortunately, each trial of a properly designed FMRI choice task can occur rapidly, on the order of seconds. This creates the opportunity to systematically test variables of interest (e.g., variation within environmental attributes in a choice experiment) within a given subject.