How neuroscience can inform energy economics

Sigrid Stagl
IAEE2009, Vienna
9 September 2009
Overview

• What is neuroeconomics?
• How can it inform energy economics?
• What do we need to be cautious about?
What is neuroeconomics?

Neuroeconomics is a subfield of behavioural economics and uses empirical evidence of limits on computation, willpower and greed to inspire new theories.

Neuroeconomics combines methods from neuroscience and economics to better understand how the human brain generates decisions in social and economic contexts.

Neuroeconomics uses knowledge about brain mechanisms to inform economic theory. It opens up the “black box” of the brain.

The neuroeconomic theory of the individual replaces the fiction of a utility-maximising individual which has a single goal, with a more detailed account of how components of the individual – brain regions, cognitive control, and neural circuits – interact and communicate to determine individual behaviour (Camerer 2007).
What is neuroeconomics?

Neuroeconomics is the study of the biological microfoundations of economic cognition (Laibson).

- Biological microfoundations are neurochemical mechanisms and pathways, like brain systems, neurons, genes, and neurotransmitters.

- Economic cognition is cognitive activity that is associated with economic perceptions, beliefs and decisions, including mental representations, emotions, expectations, learning, memory, preferences, decision-making, and behaviour.
Neuroeconomists

• About 200 neuroscientists and economists are actively working in this new field; roughly an even mix.

• Behavioural economics: more one-sided; mostly economists and very few psychologists.
Why Combine Economics with Neuroscience?

William Jevons wrote in the Theory of Political Economy -

*I hesitate to say that men will ever have the means of measuring directly the feelings of the human heart. It is from the quantitative effects of the feelings that we must estimate their comparative amounts* (Jevons, 1871).
Why Combine Economics with Neuroscience?

Around the turn of the nineteenth century, neoclassical economists made a clear methodological choice, to treat the mind as a black box and ignore its details for the purpose of economic theory.
Why Combine Economics with Neuroscience?

Rise of as-if-rational choice models in neoclassical economics.

Ignorance of psychology that Pareto explicitly advocated - cemented by Milton Friedman’s (1953) development of positive economics.

Two principles for judging theories which use assumptions \( A \) to make a formal prediction \( P \):

1. Assumptions \( A \) should be judged by the accuracy of the predictions \( P \) they mathematically imply.
2. Since false assumptions can yield accurate predictions, even if assumptions appear false their empirical weakness should be tolerated if they lead to accurate predictions \( P \).
Why Combine Economics with Neuroscience?

• Neoclassical economists ask “Given rational people, how do models behave?”
  – Rational choice theory, expected utility theory

• Psychologists ask “Why do people behave the way they do?”
  – Prospect theory, hyperbolic discounting, learning models.
  – Fairness and reciprocity models.

• Looking inside the “black box”
  – At the neuronal and biochemical level
  – To understand what makes people happy, risk seeking or averse, trusting or trustworthy and what drives preference and choice
Neuroeconomic analysis – how does it work?

• Observe subjects’ brains when they are in a decision situation.
• Find the voxels (i.e., 3D Pixel) which are particularly active in particular situations.
  • For example: Unfair vs. fair offers by humans.
• Interpret the observed activations by relating the results to studies that observe activations in the same brain regions.
• Relate the observed brain activation with behaviour.

• Brain regions are functionally specialized. At least, brain functions are not homogeneously distributed across the brain.
• Working parts of the brain show some kind of activity.
• This activity is measured with fMRI.
Basic functional anatomy

- Primary sensory areas
- „Theory of Mind“
- Working memory
- Spatial orientation
- Primary visual system
- Form recognition
- Motion recognition

Frontal Lobe
- Decision making
- Motor planning
- Higher cognition
- Moral judgment

Temporal Lobe
- Long term memory
- Language
- Object recognition

Parietal Lobe

Occipital Lobe
# Brain Imaging Techniques

<table>
<thead>
<tr>
<th>Methodology</th>
<th>What is imaged?</th>
<th>How?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electroencephalography (EEG)</strong></td>
<td>Changes in electrical brain current</td>
<td>Electrodes placed on scalp measure electrical brain waves</td>
</tr>
<tr>
<td><strong>Computed (Axial) Tomography Scan (CT or CAT)</strong></td>
<td>X-ray images of the brain</td>
<td>Multiple images (tomograms) are taken by rotating X-ray tubes. Does not image function</td>
</tr>
<tr>
<td><strong>Positron Emission Tomography (PET)</strong></td>
<td>Emissions from radioactive chemicals in the blood</td>
<td>Radioactive isotopes injected into the blood are detected like X-rays</td>
</tr>
<tr>
<td><strong>Magnetoencephalography (MEG)</strong></td>
<td>Changes in electrical brain current</td>
<td>Similar to EEG but magnetic brain waves are measured instead of electrical waves</td>
</tr>
<tr>
<td><strong>Functional Magnetic Resonance Imaging (fMRI)</strong></td>
<td>Blood flow; oxyhemoglobin to deoxyhemoglobin ratio</td>
<td>Relies on magnetic properties of blood. Shows brain function spatially and temporally</td>
</tr>
</tbody>
</table>
Why is Neuroeconomics so fascinating?

• Brain research has made great progress during the past decade, largely due to noninvasive techniques that allow observing the brain while it is active.

• Systematic study of the relation between behaviours and brain processes in healthy human subjects is possible.

• Possible to provide brain evidence in support of or challenging economic theory, allows deeper understanding of (behavioural) economics results.

• Provide genuinely new insight into the neurobiological determinants of human behaviours.
How can it inform energy economics?

Three examples of neuroeconomics research relevant for energy economics:

• Preferences
• Decision-making under risk and uncertainty
• Social preferences
Preferences

• Utility of money
• Economics: People are expected to value money for what it can purchase → indirect utility of income
• Neuroeconomic evidence suggests that money can be directly rewarding → direct utility of income
  – Monetary rewards seem to activate the same brain region (dopaminergic neurons in the midbrain) that is active for a wide variety of rewarding experiences
• Possible explanation for why workaholics and very wealthy people keep working even though the marginal utility of goods purchased with their marginal income is very low
Preferences

• Source of income
  – Economics: utility of income is independent of its source

• Neuroeconomic evidence: earned money is more rewarding than unearned money
  – Greater activity in the striatum (midbrain region) for earned income (Zink et al 2004)

• Implications for welfare and tax policies?
  – Farm subsidies vs. product revenues
  – More broadly – tax unearned money
Decision-making under risk and uncertainty

• Economics: risk is equated with variation of outcomes = one-dimensional
• Neuroeconomic evidence: risk has more than one dimension
  – Potential catastrophic outcomes that are difficult to control are perceived as more risky (controlled for statistical likelihood) $\Rightarrow$ fear of flying
  – Driven (amongst others) by fear responses (amygdala)
  – "Ambiguity": missing information about probabilities people would like to know but don’t
    • Activation of insula is different when people choose certain money amounts compared to when they choose ambiguous gambles (insula processes information like physical pain, hunger, pain of social exclusion,...)
Social preferences

• Assumption among neuroscientists: there is a specialized “mind-reading” area in the human brain, that controls reasoning about what others believe and might do

• Social preferences
  – Cooperating subjects show increased activation in “mind reading area” (Broadmann area 10), autists are assumed to have deficits in that area and often have trouble figuring out what other people think and believe
  – Sanfey, Rilling et al.: fMRI study of ultimatum bargaining
Neural Basis of Responder Behaviour in the Ultimatum Game

• Responder’s brain activations are measured by fMRI.
• A responder faces each of three conditions ten times.
  – Offers from a (supposed) human partner
  – Random offers from a computer partner
  – Money offer (there is no proposer here)
• Research Questions: Which brain areas are more activated when subjects face...
  – fair offers (3-5) relative to unfair offers (1-2).
  – the offer of a human proposer relative to a random computer offer.
• Method (very simplified):
  – Regression of activity in every voxel in the brain on the treatment dummy (i.e., unfair offer dummy, human proposer dummy)

(Sanfey, Rilling, Aronson, Nystrom, Cohen 2003)
Results

• Regions showing stronger activations if subjects face unfair human offers relative to fair human offers (the same regions also show more activation if the unfair human offer is compared to unfair random offers).
  – Bilateral anterior Insula, anterior cingulate Cortex
    • Emotion-related region
    • Insula also has been associated with negative emotions such as disgust and anger.
• Dorsolateral prefrontal Cortex (DLPFC)
  – Cognition-related region
  – Associated with control of execution of actions
  – Associated with achievement of goals.
• Unfair offers are more likely to be rejected if insula activation is stronger.
• Insula activation is related to “unpleasantness”
  – Higher for offer of unfair person.
  – Higher for more unfair offers.
  – Higher for people who reject. (unclear: Is activation the cause of rejection or a byproduct?)
What might we gain from neuroeconomics?

- Neuroscience measurements may offer more reliable and unbiased data (e.g., compared to certain survey data or self-reports)
- Impressive correlations between psychological measures and measures of brain activity, or of differences between levels of brain activity in different regions.
  - Within-subject correlation between rejection of unfair offers and the activation of right anterior insula (Sanfey and Dorris), high correlation between behavioural measures of loss aversion and a neural measure of loss aversion in ventral striatum and ventrolateral prefrontal cortex (Fox and Poldrack), and a correlation between the difference in neural measures of people’s utility for their own money and for others’ money and a willingness to donate to these others.
  - Between-subject correlations – esp. interpersonal comparison of utility. If brains are sufficiently similar in structure and function to support high correlations between indices of brain activity and measures of psychological states, the calibration function that relates the psychological to the neural variables is unlikely to be very different across individuals, and there appears to be little justification for the taboo regarding interpersonal comparison.
What do we need to be cautious about?

• Usefulness of knowing which parts of the brain are activated when particular thoughts or choices happen? Interpretation of imaging results often tricky.

• Results that confirm expectations or help to sharpen existing hypotheses are most valuable in early days of a field; negative results are more difficult to interpret.

• Critique of poor experimental and statistical foundations - ad hoc statistical evidence and storytelling, presented as truth or knowledge

• Academic marketing hype? Achievements / potentials?
• Thanks to ESRC, which funded this work.
• Next step: “Green neuroeconomics” – new project funded by Jubilee Fund of the Austrian National Bank.

I look forward to your questions and comments.

stagl@wu.ac.at