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Abstract: Neuroeconomics has the potential to fundamentally change the way economics is done. This article identifies the ways in which this will occur, pitfalls of this approach, and areas where progress has already been made. The value of neuroeconomics studies for social policy lies in the quality, replicability, and relevance of the research produced. While most economists will not contribute to the neuroeconomics literature, we contend that most economists should be reading these studies.

0. Introduction

Underneath its mathematical sophistication, economics is fundamentally the study of human behavior. Economic theory presumes that people make decisions according to axiomatic laws governing beliefs and preferences (Mas-Colell et al. 1995). However, a variety of field and laboratory experiments identify cases in which economic models fail (Thaler 1992; Camerer 2003). For example, consider the payment of taxes. Most of us pay taxes with little coercion and entrust them to a government that is physically and perhaps politically distant. The payment of taxes is based on the expectation that government services will be provided. This expectation depends on trust that the implicit contract with the government will be upheld. When trust fails, compliance with the tax code drops (Slemrod 1992).

Why should we trust the government with our hard-earned money? First, we are compelled by law to do so, and the risk of being prosecuted for nonpayment is clearly important. But the risk of an audit is very low, and yet many of us spend a substantial amount of time and money preparing our taxes, trusting that the provision of services will occur. Second, many people say that it is 'fair' to pay one's share of taxes (Slemrod 1992). Trust, enforcement, and fairness are leading explanations for tax payments, but trust and fairness are outside of realm of standard economic analysis. These largely 'internal' factors that motivate behavior are rich areas for neuroeconomics studies.

Trust is amenable to neuroeconomics experiments because *i)* it can be modeled mathematically; and *ii)* it can be reliably produced in a tightly-controlled laboratory setting. The former condition is important because it allows a derivation of equilibrium behavior, that is, a prediction of what people will do when faced with a trust decision. The latter condition permits one to test whether observed behavior conforms to predicted behavior. It also allows one to carefully vary the conditions of the experiment to see whether this changes behavior closer to, or further from, the equilibrium.

Laboratory studies of interpersonal trust have used a model called the 'trust game' (Berg et al. 1995). A vast number of studies have shown that under almost every variant imaginable, almost no one plays the equilibrium strategy in a one-shot game. Indeed, those who do have elements of sociopathy and exhibit evidence of a brain disorder (Zak 2005). Neuroeconomics studies have made substantial progress in understanding why we trust strangers and reciprocate when trusted (Zak 2007). These studies show that we trust others using cognitive mechanisms associated with determining others' likely choices (McCabe et al. 2001); reciprocate because our brains make cooperation rewarding (Rilling et al. 2002; King-Casas et al. 2005; Tomlin et al. 2006); and permit ourselves to trust because to a hormone called oxytocin that reduces our fear of interacting with others and motivates us to reciprocate when trusted (Zak/Kurzban/Matzner 2004; 2005; Kosfeld et al. 2005).

The subgame perfect Nash equilibrium (SPNE) of the trust game predicts an absence of trust and trustworthiness (the reciprocation of trust). *Homo economicus* does not trust and is never trustworthy. He does not connect to, or rely on, others. Yet the neuroeconomics studies above, as well as the behavioral studies that preceded them, show that trusting a stranger is a pervasive human behavior. The deviation of theory from observation points to the need for improved models of trust.

The traditional economic approach to building models is to cogitate for weeks or months in one's office and then write down a mathematical model (Varian 1999). This model may or may not yield novel behavioral predictions, and may or may not be tested (or be testable). These factors reduce the number of scientifically valid discoveries in economics. Most economists are convinced that in many strategic settings, the standard model of narrow self-interest is incorrect, and an active literature is seeking to fill this gap (Fehr/Gachter 2002; Rabin 1993, Gintis 2007; Zak 2008a; 2008c). This push is being led by behavioral economists and more recently, by neuroeconomists (e.g. see Zak 2004). Understanding the basis for trust is not only of academic interest, but studies have shown that trust is fundamentally important for the functioning of societies and reducing poverty (Zak/Knack 2001; Zak 2008).

The standard deductive approach of modern economics is based largely on twentieth-century physics (Zak/Denzau 2001; Hodgson 2001). The alternative, an inductive approach closer to that used in biology, works at getting the assumptions of models correct, rather simply focusing on predictive power. This focus on assumptions first and then prediction is counter to traditions in economics (Friedman 1955). Nevertheless, this approach is consistent with a large literature in the philosophy of science in which the search for causal mechanisms requires that the assumptions of models are consistent and verifiable, rather than those that simply predict a data series (Rosenberg 2005; Dennett 1995). We can go further: because human beings are biological creatures and face biological constraints, the tools of biology are useful to characterize human behavior. It is our view that human behavior cannot be understood except under the lens of evolution (see Zak/Denzau 2001). Evolution provides the framework to assess goals and constraints from which behavior arises.

1. Neuroeconomics Research Tools

Neuroeconomics studies measure brain activity during decisions in order to predict behavior. The use of money in neuroeconomics experiments provides objective measures of what people care about. Money allows one to compare behaviors between subjects within a treatment, and within subjects across treatments. Money is a means to an end and not an end in itself. There is typically no deception in neuroeconomics, following the lead of experimental economics. This approach is meant to produce clear behavioral outcomes as experimental participants have no reason to 'game' the experiment to see what the experimenters are 'really' measuring (Ortmann/Hertwig 2002). Abolishing deception is therefore expected to increase data reliability. The lack of deception also means that participants really get paid for the decisions they make, rather than making hypothetical decisions or receiving course credit for participation as in many psychology experiments (Croson 2005). It also preserves the subject pool who, if deceived, might tell others about the deception.

Decisions are then correlated with measures of brain activity. Because most areas of the brain process multiple streams of data, the 'subtraction' method is typically used to link the difference in brain activity with a difference in behavior. The subtraction method measures brain activity during a control task and then removes this from brain activity during the task of interest ('treatment' task). This is similar to investigational drug studies in which some subjects get a placebo and some get the drug and differences are compared. In neuroeconomics, having the control task be close to the treatment except for a key element of interest is the art in designing experiments. By assumption (or better, via measurement), participants' characteristics across groups are similar so that differences can be attributed to treatments alone. Measuring demographic factors, gender, and personality traits permits an ex post examination of a selection bias. A criticism of this approach is that it is post hoc (Carroll 2003). Random assignment to the control and treatment groups allows one to infer causation from the discovered correlation.

Results can be strengthened by delivering varying stimuli in the same condition. This can produce a parametric relationship between stimuli and response, rather than simply differences in averages across groups. Findings from neuroeconomics experiments that do this are considered more robust (Rasch et al. 2007).

Brain activity can be measured using a variety of methods, including functional magnetic resonance imaging (fMRI), positron emission tomography (PET), event related potentials, transcranial magnetic stimulation (TMS), skin conductance, eye tracking, and blood draws. The description of these methods and their applications can be found elsewhere (Zak 2004). It is important to note, though, that the cost of most of these technologies is rapidly declining. This is good for the neuroeconomics researcher but bad for the literature. Similar to the effect on the quality of statistical studies with the decline in the cost of computer time, lower costs for physiologic measurements means experiments can be thought up and run with little forethought on design.

Causation can be directly determined by changing participants' brain states and measured observed behavioral changes, if any. This is most easily done using neuro-active drugs that 'turn on' regions of the brain. The neuroeconomics oxytocin infusion studies of Kosfeld et al. (2005) and Zak et al. (2007) are examples of this approach. Kosfeld and colleagues demonstrated that a moderate dose of oxytocin increased trust, as measured with monetary transfers, by 17%. Zak et al. (2007) demonstrated that oxytocin infusion raised generosity in an economic game by 80%. Cortical regions can also be activated or de-activated using TMS. A recent study showed that TMS changed the proportion of individuals rejecting unfair splits of money (Knoch et al. 2006). The necessity of a brain region to the task in question can be demonstrated using patients with focal brain lesions. The combination of methods shows convergent evidence for neural mechanisms. For example, Hsu et al. (2005) used fMRI in healthy adults and the same behavioral task in patients with brain injuries to produce causal evidence for a brain mechanism involved in decisions with ambiguous outcomes.

2. Recent Findings and Implications

Economists since Daniel Bernoulli (1700-1782) have assumed that human beings have utility functions that map external rewards into subjective values. The myth of the evaluation the 'utils' of various choices has been confirmed by neuroeconomists. Several regions of the primate brain appear to be physiologic utility functions. That is, neurons in these region fire at increasing and concave rates as rewards increase, both in absolute value and in expectation (Glimcher 2003; Knutson et al. 2005; 2007; Nelson et al. 2004; Kucian et al 2005).

Identifying the physiologic utility function is important for several reasons. First, it substantiates the most fundamental assumption in economics. Because we now know that utility functions are real physiologic entities, the utility calculations that people were assumed to do really happen in brain. We think every introductory economics course should begin with this piece of information. Second, it permits, for the first time, direct interpersonal utility comparisons. The 'common currency' in the brain is neural firing rates. These can be used to predict behaviors as varied as risky choices, consumer purchases, and fashion trends (Zak 2004; Knutson et al. 2005; 2007; Kuhnen/Knutson 2005; Camerer/Loewenstein/Prelec 2005, Sutherland 2006). For example, women are generally more risk averse than men and neural firing rates predict differences in risky choices. Because these brain regions have been identified, we can dig further and examine the basis for differences in risk aversion, from genetics to life histories. This knowledge can be used to refine policy planning and identify possible adverse outcomes from policy changes. For example, the U.S. is currently debating giving individuals the right to privately invest part of their social security benefits in stocks or government bonds. The benefits from stock investments in such a program will not arise if those eligible are highly risk averse, while the costs of setting up such a system will still have to be paid.

Third, knowing where the utility function is in the human brain allows us to study intrapersonal variation. For example, variation over time, temperature, physical environments, and physiologic states may affect choices, and by measuring the brain's utility function we can understand why and how behavior changes. For example, most of us buy more at the grocery story when we are hungry. The functioning of the utility function across levels of hunger may provide novel insights into this behavior because the brain runs on glucose. The firing rates of brain's utility function also appear to concord with prospect theory (Breiter et al. 2001, Tom et al. 2007). Neuroeconomics studies permit a direct measurement of why losses are more strongly experienced than gains, and under what conditions, by measuring neural firing rates.

Neuroeconomics is also providing new insights into another important issue in economics: 'rationality'. The traditional view in economics is that decisions are made after careful deliberation of costs and benefits determined through one's preferences and the constraints faced. Rationality is defined in economics as, essentially, consistency in choices. Neuroscience research is showing that most brain processes are unconscious; an 'interpreter' region in the left hemisphere appears to provide an the ex post commentary in our heads for decisions we come aware of only after brain activity determines the choice (Gazzaniga 1998). This suggests that the economic model of thoughtful deliberation is wrong. The open issue is where to make changes: in preferences or in constraints. The correct answer is probably in both. For example, neural firing rates are highly stochastic, suggesting a basis for variety-seeking in consumption that casual observation shows occurs. Stochastic neural activity also suggests that constraints may be stochastic. Variable preferences and constraints can quickly lead to intractable models without predictions at all. Adding findings from neuroeconomics studies into economic models while maintaining solubility is a difficult balancing act; preliminary models that do this are starting to appear though (Bernheim/Rangel 1994; Brocas/Carillo 2006).

An additional wrinkle in modeling preferences is that the brain is a highly adaptive organ that is constantly learning and responding to new information. To be tractable, standard economic models require that individuals have preferences over all possible goods. Kahneman and Snell (1992) have shown that people have poorly defined preferences over goods they have not experienced. This calls into question the stability of preferences. For example, if the price of coffee rises so high that you begin to consume tea for the first time, you will not only have a new item in your utility function, but its utility relative to coffee may change over time. Further, if you consume enough tea, you may eventually lose your preference for coffee altogether. For instance, many diet programs are based on a preference shift for foods. Stochastic and dynamically evolving preferences are difficult to square with the standard view of rationality.

Another area in which neuroeconomics studies are providing new insights is choices that involve others. As discussed above, trust among humans is higher than predicted by most economics and biological models. More generally, cooperative behaviors, especially with strangers, are higher than predicted. We are hyper-social apes, and brain activity during strategic choice reveals how strongly others' interests and even others' presence resonate when we make choices. An important finding from neuroeconomics studies is the role of evolutionarily old brain structures in supporting trusting behaviors (Zak 2007). Many of the brain regions that produce trust and reciprocity are associated with emotional responses—we appear to have a 'gut instinct' about who to trust and who to avoid. This intuitive, emotional approach to trust, rather than a cognitive deduction based on costs and benefits, indicates that an economic model that gets the assumptions right will be much more complicated than either a purely-self-interested model or the newer models that weigh one's own and others' outcomes (Rabin 1993; Camerer 2003). Changing environments, life-histories, genes, and even whether one has eaten a meal recently all affect brain functioning and therefore may impact the decision on whether to trust another. While the eventual model of trust that comes out of this research will be less mathematically tractable than older models, it should provide better predictions overall, and more importantly, sharper predictions across environments and individuals (see Zak 2008c).

Another example of neuroeconomics studies of strategic behaviors are experiments using the ultimatum game (UG). In the UG, one person, endowed with money, offers a split of it to another person. The second person can accept the split or reject it; if accepted, the money is paid, if rejected, both people earning nothing. The SPNE is to offer the smallest amount possible, for example, $1, and for this to be accepted. The logic here is that, from the second person's perspective, some money is better than no money. In the U.S., the average offer by those proposing splits is just below one-half of the endowment. Offers less than 30% of the endowment are almost always rejected, resulting in a costly punishment for stinginess (Camerer 2003). The traditional view is that choices that deviate from the SPNE are 'irrational'—why throw away good money?

A neuroeconomics study of the UG found that a region in the brain associated with visceral states such as disgust (the anterior insula) was highly active in those offered a stingy split of money compared to fair offers (Sanfey et al. 2003). These researchers found that subjects rejected low offers because they were literally disgusted by them. Because the insula is an ancient brain region, this indicates that rejections in this one-shot game were not carefully 'rationally' considered, but emotional, visceral, and rapid.

In a similar game that included cost-free or costly punishment of those who violated sharing norms, men had strong activation in mid-brain regions associated with reward when punishing others. Our brains appear to produce a rewarding sensation when punishing those who violate social rules (de Quervain, et al. 2004; Delgado, et al. 2005). In a related finding, our lab discovered that an intentional decision to distrust someone by sending them a low or zero monetary transfer causes a spike in dihydrotestosterone, the 'high octane' version of testosterone, in the person who is distrusted (Zak/Borja/ Matzner/Kurzban 2005). This indicates that the reaction to being distrusted, which is much stronger in men than in women, is a desire to physically punish the other. Not surprisingly, those who are distrusted have little motivation to share resources with the other person.

Neuroeconomics studies of punishment identify an important role for emotions. From an evolutionary perspective, having a neural basis for punishment makes perfect sense. Free-riding is reduced through the threat of punishment. Because we are highly social creatures, we unconsciously evaluate the moral nature of others' behavior. We prefer to be around those who are fair, honest, and trustworthy, and avoid or punish those who are not. This approach is inconsistent with the standard view in economics in two ways. First, it recognizes that not all decisions involve cognitive deliberations. Social violations of many types are automatically and quickly felt through emotional and visceral responses (Zak 2008b; Casebeer 2003). Second, the brain is imperfectly tuned to make one-shot decisions with strangers. Our brains appear to react as if all social decisions are part of a larger set of interactions. This was likely the case during our evolutionary history when we lived in small bands of 150 people or less. The decline in cooperation with repeat play in many dyadic decisions shows that we can learn to be less cooperative (or more cooperative if our partner is cooperating).

Positive social interactions, as Adam Smith noted in The Theory of Moral Sentiments (1759), is largely driven by 'fellow-feeling', or what today we would call empathy. The hormone oxytocin, which facilitates attachment to offspring, mates, and friends, can be considered a physiologic signature of empathy (Zak 2007). As mentioned above, infusing oxytocin into human brains increases trust and generosity. It seems to do so by increasing emotional concordance between those who are interacting. These neuroeconomics studies support Adam Smith's view that emotions guide social decisions. When seeking to obtain another's cooperation, Smith wrote that "Man, ... rejoices whenever he observes that they adopt his own passions, because he is then assured of that assistance; and grieves whenever he observes the contrary, because he is then assured of their opposition. But both the pleasure and the pain are always felt so instantaneously, and often upon such frivolous occasions, that it seems evident that neither of them can be derived from any such self-interested consideration" (Smith 1759).

Neuroeconomics studies revealing the role of emotions in strategic choice will profoundly change economic models. A concrete example comes from the trust game. The SPNE predicts both people in a dyad will earn just the show-up amount, often $10 (since no transfers are predicted to occur). It our experiments in which nearly all subjects deviate from the Nash strategy, on average, those who trust earn $14 and those who are trusted earn $17 (Zak/Borja/Matzner/Kurzban 2005). Clearly, subjects are using additional information to improve on the SPNE outcome. Viable alternatives to SPNE predictions of game theoretic models need to take into account Smith's 'fellow-feeling' or empathy. Yet, this issue is nuanced. Social, physical, and emotional distance all modulate our empathy for a dyadic partner, and thus the information we have about the other affects the relative amount of pleasure or pain felt upon cooperation or rejection (Zak 2008b). As discussed above in Zak, Borja, Matzner and Kurzban (2005), there are also gender differences not only in behavior, as has been found by others (Eckel/Grossman 2001), but in the way the brain processes signals of cooperation and noncooperation. Other factors may also affect that way the brain processes information, including genetic predispositions, developmental history, recent life events (stressors, positive encounters), age, handedness, and likely many more.

An example of this approach is a neuroeconomics study that examined individuals' beliefs about others' beliefs—a key notion in game theory. Initially, beliefs differentially activated prefrontal areas of the brain. But when people reached an equilibrium in beliefs, a 'neural equilibrium' was also found in which there was no discernable differential brain activation (Bhatt/Camerer 2005). Further, these researchers found that earnings from accurate beliefs were positively correlated with mid-brain reward activity, while poor strategic thinkers earned less and this was associated with activity in the insula.

We envision the next wave of economic models to be of the 'rational choice plus' variety. That is, utility maximization will be maintained, but additional utility flows and constraints will be present. Only careful additional studies will identify which factors provide sufficient predictive power to be included and which can be ignored. Besides findings from neuroscience, augmented economic models will also likely include results from sociology, anthropology, psychology, and other fields. These can usefully be incorporated into economic models through the common pathway of the brain. The neuroeconomics approach to modeling seeks to put humans back into the social science of economics.

3. Implications and Uses of Neuroeconomics

As Paul Samuelson quipped, "funeral by funeral, theory advances". Like any new field, neuroeconomics has its critics (Gul/Pesendorfer 2005). We maintain that economists are behavioralists--we build and test models of human behavior. These models can be improved by new findings from neuroeconomics studies. Behavioral economics, which incorporates psychology into economic models, has improved a variety of predictive models by incorporating factors like temptation and self control (Gul/Pesendorfer 2001).

Neuroeconomics has a nearly unique ability to contribute to building models that improve predictions because experimental subjects are poor at reporting the rationale for their decisions. This poor reportage may be due to the substantial amount of unconscious processing we do of environmental stimuli. The roles of unconscious and emotional factors in choice have important implications for policy design and institutional structure. Because people do not clearly know what they want without experiencing the outcome, small scale policy experiments are called for. For example, it is difficult for many people to delay gratification. Delaying rewards can be traced to prefrontal inhibition of reward regions of the brain (McClure 2004). Institutions that 'tie our hands' to improve long-term outcomes can be designed to combat this tendency. For example, Richard Thaler has designed employee savings programs that increase pension contribution rates only when employees receive a raise (Sunstein/Thaler 2003).

Institutional design to stimulate economic growth can also benefit from neuroeconomics studies. Because interpersonal trust is a powerful predictor of economic growth (Zak/Knack 2001), knowing how to raise trust is a development priority. The role of oxytocin, and more generally empathy, in building trust has clear implications for institutional design to increase trade. Specifically, a substantial amount of trade is personal (or personalized), and therefore building personal ties, within an environment of contract enforcement, can increase trust. For example, Bangladeshi Muhammad Yunus loaned $27 to forty two stool makers in a tiny village to help them purchase the raw materials. Yunus eventually started the Grameen Bank to stimulate economic development at the personal level. He was awarded the Nobel peace prize in 2006 for his efforts. He reports that his initial loan was made because of empathy for these impoverished people (Yunus 2003). Context matters in institutional design.

The incorporation of Adam Smith's moral sentiments into economics also has implications for economic regulation and law (Zak 2008a; 2008b). As discussed above, moral violations are, for most of us, rapidly and deeply felt. This motivates us away from behaving in social unacceptable ways. But when moral violations are directly monitored and punished, paradoxically their incidence may increase as social acceptance is achieved by paying a fine (Gneezy/Rustichini 2000; Fehr/Gächter 2002). The neuroscience research on moral behaviors bears this finding out (Casebeer 2003). An implication of these findings is that moderately regulated economies are the best at promoting human welfare both by reducing the deadweight loss of regulation, and by recognizing the dignity of people to self-regulate. The shadow of enforcement is critical to build confidence during exchange, but neuroeconomics studies suggest that intrusive oversight is counterproductive.

Laws themselves, since the time of Supreme Court justice Oliver Wendell Holmes (1841-1935), have used an economic model of deterrence. Modern common law de facto assumes that individuals want to engage in criminal activities, and punishments need only be ratcheted up to deter this behavior (Stout, 2008). Because the law has viewed people as narrowly self-interested maximizers rather than social (and moral) creatures, laws are less effective than they otherwise could be. For example, behavioral research in law suggests that the use of social punishments such as shame and ostracism may be more effective in reducing and deterring crime than incarceration, and at a much lower cost (Mcalinden 2005).

4. Conclusions

The methods of neuroscience have allowed neuroeconomists to make substantial progress in answering some of the most important questions in economics, including "Why is there poverty?", "How much regulation is optimal?", and "How do we achieve happiness?" By measuring brain activity during choice, neuroeconomics studies inform these questions and will ultimately lead to improved behavioral models. Perhaps most importantly, these new models will get closer to using appropriate assumptions regarding human nature during choice, making economic models empirically driven. Newer approaches in neuroeconomics examine direct interventions in the brain to affect decisions (Kosfeld et al. 2005;

Zak, Stanton et al. 2007). These types of studies can be used to determine whether induced differences in behavior affect welfare as well.

We have also argued that institutional economics models that seek to reduce poverty can also benefit from neuroeconomics studies. By putting human beings back into economics, predictions are sharpened and controversies can be resolved. All this is predicated upon the quality of the work. As the cost of neuroimaging technologies falls, the proportion of poorly designed and analyzed studies will likely increase. For applications, incorrect findings may be more harmful that no findings at all. Yet not all the questions in economics above require the measurement of brain activity. Simpler approaches such as field experiments may be sufficient in many cases (Harrison/List 2004), though traditional economist still balk at doing this.

While we still view building mathematical models as an important endeavor in economics, we believe the use of deductive models has been abused by economists. The "fatal conceit" (Hayek 1988) of believing one can model human beings' behaviors without observing them has lead to an enormous output of models of mostly very little value. We advocate the more humble inductive approach where data are assiduously collected, results confirmed in the field and laboratory, and then models are built. We agree with the institutional economist Thorstein Veblen who wrote

> "It may be taken as the consensus of those men who are doing the serious work of modern anthropology, ethnology, and psychology, as well as of those in the biological sciences proper, that economics is helplessly behind the times, and unable to handle its subject matter in a way to entitle it to standing as a modern science." (Veblen 1898, ?????)

Our hope is that neuroeconomics will finally move economics into its proper standing as a modern science.

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