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NEUROECONOMICS

Decision-Making through a Neuroeconomic Perspective

Bachelor's Thesis
by
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Abstract

This essay is an introduction to the interdisciplinary field of neuroeconomics. Firstly, we provide an overview of the existing theories in neoclassic economics and cognitive neuroscience, which contributed to the creation of neuroeconomics. We thus examine briefly and critically the meeting points of economics, psychology and neuroscience that remain important for the evolution of economic thought. The concepts of *homo economicus*, bounded rationality, satisficing, cognitive biases and heuristics are analyzed. Subsequently, the transition from economics to neuroeconomics is presented. The tools and methods through which neuroscience can help create new improved models are listed. Neuroscience combines the fields of neuroscience, psychology and economics with the aim of understanding the way all economic and investment decisions are made. Specifically, the goal is to capture all the chemical reactions and biological processes that take place in a person's brain that are related to an economic decision. Thu, this paper presents a review of modern literature on the effect of human psychophysiology on decision making, taking into account the excretions of the nervous system (dopamine, oxytocin and serotonin), possible brain lesions, social interactions and emotions of human beings. Neuroeconomics and the various experiments that neuroeconomists have conducted enable us to monitor the activity of neurons in real time, observe how this activity depends on the economic environment, and make assumptions, whether confirmed or rejected, about how the human mind receives financial decisions. The opposing views towards the contribution of neuroeconomics in the creation of behavioral models are then listed. Finally, we present a critical review of neuroeconomics.

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To my family

Contents

Chapter 1. Scientific Data before Neuroeconomics

1.1 Introduction

Human beings have also been social beings, involved in social and economic exchanges. As Braeutigam (2012: 11) has stated:

> “From ancient bartering to global markets, human activity that consists of producing, exchanging, distributing, and consuming of goods and services, i.e., economically relevant behavior, was, is, and will be an important driver of societies.”

As a result, topics such as rationality, decision-making and problem-solving have always been important and theorists have always been adamant to shed some light in the aspects involved in social and economic life. Thus, the field of economics was created. We can describe economics, using the words of Alfred Marshall (1920: 1, in Braeutigam 2012: 11):

> “Economics is a study of mankind in the ordinary business of life; it examines that part of individual and social action which is most closely connected with the attainment and with the use of the material requisites of wellbeing.”

Neoclassical economics have introduced rational choice theory which is based on the model of *homo economicus*. The basic premise of rational choice theory is that aggregate social behavior results from the behavior of individual actors, each of whom is making their individual decisions. According to the model of *homo economicus*, individual preferences are self-interested. Individuals in this case act as if balancing costs against benefits to arrive at action that maximizes personal advantage. (Calnitsky and Dupuy-Spencer 2013: 3, Foka-Kavalieraki 2017: 15, Dow Schüll et al. 2011: 516), Swanson 1996: 735)

However, it has been proven that people often fail to design ‘rational’ decisions. Economic agents are subjected to multiple biases, which affect the way they perceive events, act upon them and learn from experience. Especially, experiments conducted by Kahneman and Tversky (1979) pointed out phenomena that contradict the principles of *homo economicus*. These findings and various other experiments and studies made it clear that the existing economic and decision-making models needed to change in order to better describe the human psyche, rationality and decision-making processes. (Glimcher and Fehr, 2014: xix)

Subsequently, the interdisciplinary field of Neuroeconomics was created. Neuroeconomics has bridged the contrasting fields of economics, neuroscience and psychology. Economics, psychology, and neuroscience are converging today into a single, unified discipline with the ultimate aim of providing a single, general theory of human behavior. Economists and psychologists are providing rich conceptual tools for understanding and modeling behavior, while neurobiologists provide tools for the study of mechanism. The goal of this discipline is thus to ground economic theory in details of how the brain works in decision making, strategic thinking, and exchange, to understand the processes that connect sensation and action by revealing the neurobiological mechanisms by which decisions are made. (Camerer 2007: C38)

1.2 Neoclassic Economic Theory

The aim of research on economic decision-making is to understand how subjects choose between plans of action (lotteries, gambles, prospects) that have economic consequences. (Trommershäuser 2011: 4) Thus, various psychological theories have influenced economic science. Even from the time of Adam Smith, economics have been systematically investigating the aspect of human behavior inside the context of market, but also outside of it, the motives, decision making and human welfare. (Foka-Kavalieraki 2017: 10) According to Calnitsky «neoclassical economics posits that the macro-level reality of the market is no more than a scale model of the actions of this 'representative agent'». (Calnitsky 2013: 3)

Neoclassical economic theory or the theory of rational choice theory (TRC) is a model of explanation used by social sciences theorists in order to interpret human behavior. (13 Graziano, 2013: 3) This model is based on the principle that society is formed by self-interested individuals who have different preferences and desires and rationally pursue opportunistic behavior in order to maximize their pleasure and minimize their pain, in spite of the physical or social restrictions, such as the uncertainty of future. Thus, the heart of the neoclassical analysis lies on the concept of *homo economicus*. (Calnitsky and Dupuy-Spencer 2013: 3, Dow Schüll et al. 2011: 516, Foka-Kavalieraki 2017: 15, Swanson 1996: 735)

In other words, neoclassical economics are based on the postulate that economic phenomena are a result of the action of agents who are fully rational, equal and therefore indistinguishable from each other and they all pursue their own personal and individual gain. (Graziano, 2013: 3) According to the dominant interpretation of neoclassical theory, human beings are rational, which means they have preferences and desires that they try to satisfy through their choices. Economists state that preferences are purely subjective. The preferences they study are the ones that are expressed through market. In more detail, people are rational because they set goals in order to satisfy their subjective preferences and at the same time, they try to maximize their pleasure through satisfying their preferences in the best way possible. (Foka-Kavalieraki 2017: 16-17)

As a result, each agent compares opportunities and either chooses the choice that causes them the greatest profit or the lesser evil, either of which will be more advantageous for him according to his beliefs. In brief, this option maximizes the difference between its costs and its advantages. (Graziano, 2013: 3-4) This process presupposes that the subject is aware of his or her preferences, restrictions and available choices and chooses the one that will maximize his / her benefit. According to Camerer (2005, 1 in Clarke 2014: 201), the agent makes decisions via a specific dual process:

"Two processes, in the brain—one for guessing how likely one is to win and lose, and another for evaluating the hedonic pleasure and pain of winning and losing and another brain region which combines probability and hedonic sensations".

However, Camerer then claims that we are likely to find psychological data that contradict this cognitive hypothesis and that the TRC model has failed in many laboratory tests. (Clarke 2014: 201, Park and Zak 2007:47)

1.3 Principles of Rational Choice Theory

The other important element in decision-making is the presence of specific "constraints" that make the choice necessary and also illustrate the "pros and cons" of all the possible alternatives. The four axioms of rational choice are, namely, reflexivity, completeness, transitivity, continuity and independence.

First, when it comes to different possible options, the preferences should always possess a value equal to themselves. Preferences must therefore be reflexive: ($x_i = x_i$). This condition is purely a formal necessity and depends on common sense. For example, if two goods are exactly equal, then the agent must be indifferent. Thus, if ($x = y$), then ($x \sim y$).

The second axiom, completeness, is necessarily involved in the structural formation of the agent's preferences. It is agreed that between two different preferences the individual will make comparisons and will either choose one of them or will be indifferent. As a result, the preferences can be ordered: ($x \geq y$) or ($y \geq x$) or ($x \sim y$).

Third, the scale of preferences must be transitive, i.e., it must conform to the classic example showing that if a person prefers an orange to an apple and an apple to a pear, then he must also prefer an orange to a pear. Thus, between three different choices x, y, z, if $x > y$ and $y > z$, then $x > z$. In the same way, if $x \sim y$ and $y \sim z$, then $x \sim z$. The order of preference is a reflection of an internal coherence. There must be no ambiguity.

Fourth, an agent's preferences must be constant. When choosing between two goods, the agent will prefer one of them because it offers him grater profit. But between those two goods, there will definitely be another one, which creates less profit than the first good and grater profit than the later. Preferences are, thus, constant. Generally, if there are two sets of goods (x, y) and $x > y$, there will definitely exist a third one, z, which will result to $x > z > y$.

Fifth, the axiom of substitution points out that there is no good that is absolutely necessary to a set and that cannot be exchanged for another. For instance, for two goods x and y, there are at least two sets of goods A (x_1, y_1) and B (x_2, y_2), where $A \sim B$ and $x_2 < x_1$

and y2 > y1. Thus, the main point is what amount of x the agent is willing to sacrifice for every extra unit of y. [1]

Finally, according to the independence axiom, if there are two sets of goods, A and B, and two goods, x and y, and if these sets contain the same amount of x, the agent will prefer the set which will contain the biggest amount of y.

Thus, the order of preferences is determined by the axioms of reflexivity, transitivity, and independence, whereas completeness, substitution and continuity are the conditions that allow a representation of the utility function. (Graziano 2013: 4)

1.4 Neoclassic Revolution

The model of *homo economicus*, which described human behavior as a rational effort to maximize utility, led neoclassical theorists to the development of a coherent basic mathematical framework. Nonetheless, this model was widely criticized and the work of scholars like Allais and Ellsberg indicated that there were various examples that agents do not always make rational decisions. (Glimcher et al. 2005: 214)

Firstly, the French economist Maurice Allais designed a series of experiments with pairwise choices which led to reliable patterns of revealed preference that violated the central "Independence" axiom of expected utility theory. This pattern was later called the "Allais paradox" at a conference in France. One of the participants was Savage, the founder of subjective expected utility theory, who also made choices which violated his own theories. Allais' paradox was based on the idea that a certain outcome may be perceived as more desirable, in a qualitatively different way, than any random outcome, even if very likely. A few years later, Daniel Ellsberg (1961) presented a famous paradox suggesting that the "ambiguity" (Ellsberg's term) supporting a judgment of event likelihood could influence choices, violating one of Savage's key axioms. The Ellsberg paradox is a formal falsifications of expected utility theory. The Allais and Ellsberg paradoxes thus proved that expected utility theory as originally proposed could only predict choices under some circumstances and led to the argument that the neoclassical models worked, but only under some limited circumstances. (Camerer 2007: C33, Glimcher and Fehr 2014: xix, Glimcher and Rustichini 2004: 450, Levin 2012: 79)

The notion that humans cannot be treated as subjects who aim at maximizing their utility led to the neoclassical revolution. This notion has nowadays become unquestionable and has led to radical changes in the second half of the twentieth century. A few years after Allais and Ellsberg's findings, Herbert Simon (1997) also concluded that it is possible for humans to operate rationally by maximizing their utility only in a bounded sense. (Glimcher

[1] We have to keep in mind that the substitution rate is not stable due to the *law of diminishing marginal utility*. According to this law, the more amount of a good is consumed by an agent, the lesser he will enjoy every extra unit of that good.

2005: 215, Glimcher et al. 2005: 215). Their experiments thus lead many scholars, particularly psychologists and economists, to set, through empirical critiques, counterexamples of the simple axiomatic approaches. This process resulted in the creation of more general axiomatic systems that were more sensibly rooted in principles of psychology. (Glimcher and Fehr 2014: xix)

'[I]t has become abundantly evident', wrote neuroscientists Cohen and Blum (2002: 197), 'that the pristine assumptions of the "standard economic model" - that individuals operate as optimal decision makers in maximizing utility - are in direct violation of even the most basic facts about human behavior'.

In other words, the model of *homo economicus*, which supposes hypperrationality of individuals, has been rejected in favor of more realistic models of human behavior that incorporate insights from psychology. Especially, *behavioral economics* have attributed to the establishment of new, more realistic models of decision making. (Levine 2011: 287, Calnitsky and Dupuy-Spencer 2013: 6)

The purpose of behavioral economists has been to explain human behavior, which is not always rational. For example, in experiments conducted on subjects who state that they prefer A to B and B to C, they do not typically select A instead of B and C. (Camerer et al. 2005: 10) Another example, described by Stuphorn (2005: R247) is that of a smoker who recently decided to quit smoking but when a friend offers a cigarette he accepts the offer. His attempt to quit failed within the first month, just like 81% of others that tried. This example illustrates the fact that we often choose self-defeating behavior rather than promote our self-interest, preferring short-term tempting alternatives rather than long run optimal ones. Various similar examples promoted the need to establish more realistic model that would involve the wide range of human behavior, even if it involves irrational decisions.

There are cases where people behave rationally and cases where they behave completely irrationally. Following these observations, more and more economists have begun to believe that subjects can behave in two different ways. One is a bounded rational process which can be described by prescriptive economic theory, whereas the other can only be described empirically, as it is irrational. (Glimcher et al. 2015: 215) Initially, economists argued that these two mechanisms coexist in the human brain as two distinct mechanisms. The non-rational mechanism was explained by the limitations imposed by the biological structure of the neurons while the rational was considered to be a conscious process that somehow transcends the biological constraints. Camerer in 2003 suggested that human decision-making can be viewed as the product of one cognitive and one affective (or emotional) system and that these two systems co-exist as independent entities within the neural architecture due to their different evolutionary origins. (Glimcher 2005: 216),

As a result Glimcher and colleagues (2005: 214) pointed out that, over the last two or three decades, economists have adopted one of two basic approaches. They either argue that rational decisions based on utility theory occur only under some conditions and that defining those conditions is of great importance or they argue that standard utility theory requires modifications, additions, or new approaches, because as MIT neuroeconomist Drazen Prelec (in Dow Schüll 2011: 518) put it:

"Utility maximization has the advantage of being mathematical and precise, but the flaw of being incorrect."

1.5 Behavioral Economics

Although economic rationality has affected many areas of the social sciences, from the inside out through Becker and the Chicago School, psychologists offered an external control over the prevailing economic thought, which led to the establishment of *behavioral economics*. This branch of economics is a combination of cognitive psychology and economics. (Foka-Kavalieraki 2017: 80) The neoclassical school was characterized by a clear theory and sharp predictions but behavioral economists contributed to the falsification of elements of that theory with compelling empirical examples.

The main aspect of behavioral economics is that it has pointed out, through detailed empirical descriptions of human behavior, that subjects appear to systematically violate the principles of *homo economicus*. Most importantly, Herbert A. Simon played a principal role in the undermining of the *homo economicus* model, when he coined in 1957 the term of *bounded rationality*.[2] Later on, Amos Tversky and Daniel Kahneman developed an alternative decision making model under uncertainty, the so called *prospect theory*. Alongside their student, Richard Thaler, they contributed even more in the developed of *behavioral economics*. They carried out various empirical psychological experiments that undermined the *homo economicus* model. In their experiments they concluded that subjects use heuristic methods in the process of decision making which creates various cognitive biases. (Foka-Kavalieraki 2017: 80-82)

More specifically, in the late 1970s and 80s, Kahneman and Tversky (1979), and others, conducted several remarkable experimental examples that pointed out a range of phenomena that fell outside classical expected utility theory. The range of these phenomena was much broader than Allais and Ellsberg's examples had suggested. Whilst studying the foundations of economic choice, they replicated in experiments many common choice behaviors that conflicted with fundamental axioms of choice. (Glimcher and Fehr 2014: xix)

More recently, there have been similar findings in the field of *behavioral economics*. For instance, Elizabeth Anderson (2000: 173) states that we are poor judges of probabilities, we cannot consistently order preferences, and we do not address risk in the perspicacious manner of the rational man. In other words, we systematically seem to violate the logical

[2] He coined this term in his pioneering research into the decision-making process within economic organizations, for which he won the Nobel Prize in Economics in 1978.

implications of decision theory. Moreover, John Conlisk (1996: 670-672), summarizes a vast amount of empirical literature in psychology, pointing out evidence which demonstrate that people can make many reasoning errors which undermines the standard theory of optimization behavior.

Influenced by these experiments and findings, *behavioral economists* argued that psychology provided several evidence and ideas that could improve the model of human behavior inherited from neoclassical economics. Thus, behavioral economics proposes models of limits on rational calculation, willpower, and self-interest, and using several tools, such as mathematical theory, experimental theory and data and analysis of several field data, it attempts to codify those limits formally. (Glimcher and Fehr 2014: xix-xx)

When it comes to rational choice models, Camerer et al. (2005: 55) state that they are least useful when it comes to the way subjects think about abstract, complex and long-term tradeoffs. They believe that these models prove to be most useful in describing the simplest kinds of decisions humans and other species make, such as motor movements, perceptual tradeoffs and foraging for food.

Finally, it is important to state the connection between behavioral economics and the human behavior in the market. According to Mcmahon (2015: 147), *behavioral economics* nowadays couples different policy techniques with a regime of positivist, social–scientific truths about the market. It aims in finding out what exists in reality, such as governable but, at the same time, free subjects, interests and populations, and based on their behavior in the market it subjects them to the division of truth or falsity. Additionally, behavioral economics wants to develop, intersperse and institutionalize economic rationality. In the same time, its goal is to discipline agents to act more rationally on the market in order to enforce market logics. (Mcmahon 2015: 138)

1.6 Bounded Rationality and Satisficing

First, political scientist Herbert A. Simon had proposed that decision makers are characterized by a *bounded rationality*, and had offered a model in which utility maximization was replaced by "satisficing". (Kahneman, 2003: 1449, Levin 2012: 79) According to Simon, economics focus on the empirical study of the limits of individuals' ability to calculate when faced with a choice and how these limits therefore affect real economic behavior. (Graziano 2013: 15)

Corcos and Pannequin (2011: 23) stated that the concept of rationality could be understood from two different perspectives, one being the standpoint of making a decision, in the strict sense, and the other being from the standpoint of a meta-rationality of the decision that questions the process of choosing. This distinction is evident in the work of Herbert Simon (1947, 1976) who made the distinction between substantive and procedural rationality. On one hand, *substantive rationality* includes the suitability of behavior in view of fixed goals, taking into account the contextual constraints, and thereby enables the coherence of decision-making to be assessed. On the other hand, procedural rationality, integrates the imperfection of human decisions and points out the rationality of decision-making processes. This idea was asserted by Simon in 1947, with his concept of "satisficing" to characterize decision-making methods that lead to satisfactory, though not optimal, solutions. He concluded that:

> "Both from these scanty data and from an examination of the postulates of the economic models it appears probable that, however adaptive the behavior of organisms in learning and choice situations, this adaptiveness falls far short of the ideal of 'maximizing' postulated in economic theory. Evidently, organisms adapt well enough to 'satisfice'; they do not, in general, 'optimize'". (Simon 1956: 129 in Calnitsky and Dupuy-Spencer 2013: 7).

Herbert Simon believed that people cannot avoid restrictions in their ability to perceive various situations, analyze data, recall facts, and create solutions for their problems. They try to satisfy their preferences, doing the best they can, given these cognitive constraints of the human nature. As a result, they achieve, not the maximizing of their behavior, but the pursuit of satisfactory alternatives. Furthermore, he argued that subjects can solve difficult problems through easy cognitive processes. (Foka-Kavalieraki 2017: 81) He suggested that rationality is computationally bounded, and that much could be learned by understanding "procedural rationality". Simon's approach in understanding choice procedures empirically was in the form of algorithms [3] His belief was that we can achieve better understanding of the methods and the reasons why people make the choices they do through understanding the way that the machinery of cognition works. (Glimcher and Fehr 2014: xix)

Thus, he created models of artificial intelligence in order to depict which heuristic methods are used by systems characterized by limited computing capabilities in their attempt to solve difficult problems. (Foka-Kavalieraki 2017: 81) However, according to Glimcher and colleagues (2005: 214), there are some problems that occur in the bounding rationality theory. The fundamental problem is that the resultant models are characterized by little or no predictive power outside of their bounded domains. In the same time, they often fail to be parsimonious and appear ad hoc or under constrained.

[3] It is important to note that the option to "always choose the object with the highest utility" is one extreme and computationally demanding procedure.

1.7 Heuristics and Biases

The pioneering research of Daniel Kahneman and Amos Tversky[4], along with along with Richard Thaler, on human judgment, in the late 1960s and early 1970s, must also be taken into account, as they created their own perspective on bounded rationality. (Gilovich and Griffin 2002: 3) They conducted several psychological experiments which led them to empirical findings that contradicted the TRC model. Their findings also indicated that people use heuristic methods which lead to various cognitive biases. (Foka-Kavalieraki 2017: 82) It thus became apparent that the decision-making process is not as rational as it was originally thought.

The three general-purpose heuristics recorded by Kahneman and Tversky are availability, representativeness, and anchoring and adjustment. These heuristics were simple and efficient because they were based on basic computation that the human mind is evolved to make. ((53) Gilovich and Griffin 2002: 3)

According to the availability heuristic, subjects tend to mistakenly perceive the probability or the frequency of an event or phenomenon based on direct and individual data accessed through their personal memory or experiences, without taking into account the correct statistical factors that influence the occurrence of that particular event. (Foka-Kavalieraki 2017: 83) In other words, "use of the availability heuristic leads to error whenever memory retrieval is a biased cue to actual frequency because of an individual's tendency to seek out and remember dramatic cases or because of the broader world's tendency to call attention to examples of a particular (restricted) type". (Gilovich and Griffin 2002: 3)

For example, when someone is asked to evaluate the relative frequency of cocaine use in Hollywood actors, he usually automatically retrieves examples of celebrity drug-users from his memory. Another example is when we mention "horror movies", which activates instances of horror movies in someone's memory. The availability of horror movies may be used to answer the question, "What proportion of the movies produced last year were horror movies?" (Tversky and Kahneman 2002: 20) According to Tversky and Kahneman (2008: 11) "availability is useful for assessing frequency or probability, because instances of large classes are usually reached better and faster than instances of less frequent classes". Nonetheless, this heuristic is affected by other factors, too. Consequently, the reliance on availability might also lead to predictable biases. An example that illustrates this point is when someone is afraid to travel by plane this month only because he heard on the news about a tragic plane accident. He is thus influenced by his recent memory rather than the actual statistics of airplane crashes. (Foka-Kavalieraki 2017: 83, Tversky and Kahneman 2008: 11)

[4] They also won the Nobel Prize in Economics (Tversky unfortunately after his death) for having integrated insights from psychological research into economics science, especially concerning human judgment and decision-making under uncertainty and especially for formulating the alternative decision-making model of Prospect Theory.

On the other hand, the representativeness heuristic occurs when the individual judges the probability of an event based on the degree that this event is represented at the moment and not on the basis of the statistical factors that apply. (Foka-Kavalieraki 2017: 83) The representativeness heuristic generally favors outcomes that make good stories or good hypotheses. (Tversky and Kahneman 2002: 45) As Tversky and Kahneman (2008: 4) have pointed out, this heuristic might lead to serious errors, because similarity, or representativeness, is not influenced by several factors that should affect judgments of probability.

An example of the representativeness heuristic is the “hot hand” in basketball. According to the “hot hand” assumption, when a basketball player has scored many times in a row, some fans believe that this incident will affect the player’s next attempt to score. As a result, the fans expect that the player’s following attempt will also be successful, even though each of his efforts has the same probability to be either successful or unsuccessful. The representativeness heuristic might have serious consequences in more important situations of everyday life, for example when it comes to the stock markets and the way we perceive the probabilities of a stock rise or a stock decline, a process which is extremely unpredictable. (Foka-Kavalieraki 2017: 83)

The third heuristic, anchoring and adjustment, takes place when a person miscalculates the probability or frequency of an event or phenomenon, influenced by an arbitrary reference point (which is usually a number). (Foka-Kavalieraki 2017: 83)

Tversky and Kahneman (2008: 14) stated that people sometimes make estimates by starting from an initial value that is adjusted to yield the final answer. As a result, different starting points yield different estimates, which are biased toward the initial values. They named this phenomenon “anchoring” or “anchor effect”. Like the other heuristics, anchoring and adjustment can be a useful way of making judgments but it can also result in biased answers. (Chapman and Johnson 2002: 120)

For instance, let’s imagine that a person is trying to set a price on an antique chair that he has inherited. He then recalls seeing a very similar chair in slightly better condition at a local antique dealer and thus starts with that price as an anchor, and incorporates the difference in quality. In this context, the anchoring effect seems to be useful and effort-saving. However, it can also generate biased assumptions. Let’s imagine that the same person had seen (on Public Television’s Antiques Road Show) a slightly different chair that is signed by the designer and worth many thousands of dollars. If the person uses this price as an anchor, he ends up with a very high and thus biased value estimate. (Chapman and Johnson 2002: 120) Therefore, we can easily assume how the marketing strategy of different products can take advantage of this phenomenon of cognitive bias. (Foka-Kavalieraki 2017: 84)

1.8 Cognitive Neuroscience

The brain is considered to be the ultimate "black box". Camerer (2005: 9) stated that the foundations of economic theory were constructed assuming that details about the functioning of the brain's "black box" would not be known. This pessimism was expressed by William Jevons in 1871:

> "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." (in Camerer et al. 2005: 9)

Nowadays, neuroscience has shed some light in this aspect. Neuroscience is a key tool that uses various techniques, including imaging of brain activity, in order to discover details about how the brain works. It studies the brain and nervous system and gives us the ability to directly measure thoughts and feeling, which challenge the way we understand the relation between mind and action.

As Camerer and collegues said (2005):

> "This "rational choice" approach has been enormously successful. But now advance in genetics and brain imaging (and other techniques) have made it possible to observe detailed processes in the brain better than ever before. Brain scanning [...] shows which parts of the brain are active when people make economic decision. This means that we will eventually be able to replace the simple mathematical ideas that have been used in economics with more neurally-detailed descriptions.

Similarly, Aldo Rustichini stated in 2003:

> "This new approach, which I consider a revolution should provide a theory of how people decide in economic and strategic situations." (in Levin 2012: 125)

The field of cognitive neuroscience, according to Glimcher can be described as an interaction between two approaches, a neurological approach and a physiological approach. The neurological approach of the last century included the conduct of various studies in a range of behavioral tasks, involving either human patients or experimental animals with brain lesions. The behavioral results of the subjects were then correlated with their neurological lesions and this correlation used to infer function. The focus of these studies was on damage to either sensory systems or movement control systems because the outcome of these experiments was easily controllable, observable and quantifiable. In 1848, the case of Phineas Gage was a prominent example of the effects of brain damage on decision making. He exhibited a dramatic change in both his personality and decision making due to a brain damage that was caused by a steel rod that penetrated his brain. (Foka-Kavalieraki 2017: 76-77, Glimcher and Fehr 2014: xx-xxi)

By comparison with the neurological approach, the physiological approach to the study of the brain consists of more precise methodological tools, such as are the correlation of direct measurements of biological states, changes in blood flow, and changes in neurotransmitters, with events in the outside world. However, these methods are subject to a methodological constraint, as physiological measurements are invasive, and often destructive and as a result, they are only used in animals.

Due to important advances, during the period from the 1960s to the 1980s, both of these approaches developed and even fused. Various models from psychology began to be used in neurology in order to understand better the relationship between brain and behavior. This development lead to the creation of different models of mental processes and then to the correlation of intermediate variables in these models with either physiological measurements or lesion-induced deficits. For example, the first successful attempt to predict decisions from single neuron activity was achieved in the late 1980s by William Newsome and J. Anthony Movshon. (Glimcher and Fehr 2014: xxi)

Nowadays, we are able to achieve a better understanding of the relation between mental and neural function in humans due to the development of methods that depict human brain activity non-invasively. Neuroscientists use many tools, including brain imaging, behavior of patients with brain damage, animal behavior and recording single neuron activity. (Camerer et al. 2004: 555) According to Ruff & Huettel (2014), there is an increasing emphasis on brain stimulation techniques where electric, magnetic, or optical stimulation is used to manipulate the activity of specific regions of the brain, resulting in behavioral changes. One of these methods is positron emission tomography (PET) which is used to image the neural correlates to mental function. [5]

The most widely used method to image brain activity non-invasively is the functional magnetic resonance imaging (fMRI). When the functional magnetic resonance imaging (fMRI) technique was firstly used, it reinforced the hope that it would allow researchers to identify which regions of the human brain are involved in different types of decisions and ultimately to reveal people's thoughts. Given early research on other neural processes such as vision, sensation, language, and movement, this hypothesis was very reasonable. (Konovalov and Krajbich 2019: 148) It is remarkable that fMRI provides us with direct imaging of brain activity while humans engage in cognitive tasks. This event has influenced scholars in many disciplines who measure the brain activity of humans during decision making. (Glimcher and Fehr 2014: xxi)

Moreover, neuroscientists are very opportunistic about evolving and broadening the use of various methods such as single neuron recording, the animal model, computational models, psychophysical measurement like skin conductance and EEGs, fMRI, and behavior of human patients with brain lesions. These methods have the advantage that they are very precise about how brains might be computing something like a numerical utility. For instance,

[5] In its early stages, this method was limitedly used due to the need for radioactive tracers.

some studies recording single neurons in monkey parietal and frontal cortex areas suggest that utilities are expressed by neural firing rates. (Camerer 2005: 12)

At the same time, Kolovalov and Krajbich (2019: 149) notice a methodological change of focus in neuroscientific research from correlational techniques to out-of-sample predictions. For instance, multivariate machine learning techniques are nowadays used to many studies in order to determine whether spatial patterns of brain activity can predict, out of sample, what a subject is seeing or doing or even predict later behavior.

Chapter 2. The interdisciplinary field of Neuroeconomics

2.1 Neuroeconomics

Neuroeconomics is an interdisciplinary approach of human behavior which is located at the intersection of neuroscience, economics and psychology. As Carl Craver, a philosopher of neuroscience at Washington University in St Louis (in Rinaldi 2009: 823), said:

> "Economics provides descriptive tools and conceptual resources for describing human decision-making behaviour. The task of neuroeconomics is to describe the neural mechanisms that underlie human decision-making behavior".

Neuroeconomics converge around the model of *homo economicus*, a rational actor who calculates his choices to maximize his individual satisfaction. (Dow Schüll and Zaloom 2011: 516) More specifically, neuroeconomics provide evidence of situations in which utility maximization either works well, such as in simple binary choices, or detects situations in which it benefits from the introduction of behavioral constructs. There is a wide variety of experiments, such as studies of risk and time preference, finance, and neural decoding of private information that make it possible for neuroeconomics to establish theories that correlate choices with mental processes and states, such as fear or cognitive load. (Camerer 2013: 425)

Additionaly, neuroeconomics investigate the neural correlates of decision-making, in choice situations which may be of interest to the economist whilst trying to enrich or revise some theoretical assumptions of the economic science (Bourgeois-Gironde 2010: 229-230, Sanfey et al. 2006). For instance, neuroeconomists search the biological substrate of the brain in order to shed light to consumer action and answer questions such as "why people often make decisions to buy, sell, invest, and trade in ways that seem to go against their best interest". (Dow Schüll and Zaloom 2011: 516)

According to Camerer (2007: C31) neuroeconomics can provide us with different types of evidence about economic behavior, such as mechanisms that implement rational choice (utility maximisation and Bayesian integration of information), typically in tasks that are highly-sculpted to make decisions that are useful for survival across species (vision, food, sex and danger). It can also produce evidence which supports the kinds of variables and parameters introduced in behavioural economics, but also evidence which suggests the influence of 'new' variables that are implicit, underweighted, or missing in rational-choice. Such evidence contributes to the creation of new models of decision-making.

However, neuroeconomics not only contribute to the establishment of theories and models that are closer to the reality of the human behavior but also help the process of policy making. Neuroeconomics are a vital tool in the process of building models that improve predictions because they take into account factors, such as the unconscious and the emotions of the subjects, which determine human behavior. According to Park and Zak (2007: 54), these new models are important for policy design and institutional structure.

Policymakers continue to encourage citizens to pursue their own self-interests as a path to maximizing collective well-being. Nonetheless, they have also begun to search neuroeconomics in order to find a model of the human being that can lend conceptual support to economic, social, and health policies designed to address a subject different from the traditional actor. At the same time, going a step farther than behavioral economists, who argue that policy designers need to take seemingly 'irrational' choices into account, neuroeconomists insist that they need to understand how such choices get made in the brain. (Dow Schüll and Zaloom 2011: 516-517)

2.2 A Brief History of Neuroeconomics

Neuroeconomics is a quite controversial and also heterogeneous field of studies. As Clithero and collegues (2008: 2348) schematically stated:

> "We define neuroeconomics as the convergence of the neural and social sciences, applied to the understanding and prediction of decisions about rewards, such as money, food, information acquisition, physical pleasure or pain, and social interactions."

By the late 1990s several converging trends set the stage for the birth of neuroeconomics. Within the field of economics and the psychology of judgment and decision making, a critical tension had emerged between the neoclassical/revealed preference school and the behavioral school. The axiomatic model of human choice that the revealed preference theorists had created, although mathematical and elegant, it displayed shortcomings in its prediction ability and it was easily controvertible due to the easy production of counterexamples. In their effort to respond to this challenge, revealed preference theorists both made alterations to their model in order to improve it and challenged the significance of many of the existing behavioral economic experiments. (Glimcher and Fehr 2014: xxii, Rinaldi 2009: 823)

On the contrary, behavioral economists followed a different approach by searching for alternative mathematical theories and different types of data to test those theories, which they saw as claims about both computational/psychological processes and choices. They aimed at providing a different theoretical approach for predicting behavior and a methodology for testing those theories. This is an approach that benefits from good theories that predict both choices and "non-choice" data.

While various multiple agent and heuristic models were evolving in behavioral economics, a different tension was taking place between psychology and cognitive neuroscience. On one hand, psychologists were interested in single neuron studies of decision making, and on the other hand, cognitive scientists were interested in describing the algorithmic mechanisms of choice. (Glimcher and Fehr 2014: xxii-xxiii)

Their goal was to describe the neurobiological hardware that supported choice behavior in situations ranging from perceptual decision making to the expression of more complicated preferences. What they lacked was an overarching theoretical framework for placing their neural measurements into context. Newsome and his colleagues had argued that the standard mathematical tool for understanding sensory categorization, signal detection theory, could solve this problem. Nonetheless, they remained skeptical that this approach could be sufficiently generalized. Subsequently, Glimcher and colleagues (2014), suggested that a useful theoretical tool for neuroscience would be the neoclassical/revealed preference framework. As a result, concepts such as expected value and expected utility were rapidly introduced into the neuroscientific literature.

Neuroeconomics thus emerged from a heterogeneous mix of scholars, spurred by the tools of neurobiology to analyze the molecular and physiological mechanisms by which decisions are made. Behavioral economists and cognitive psychologists viewed functional brain imaging as a tool to both test and develop alternatives to neoclassical/revealed preference theories, whereas physiologists and cognitive neuroscientists used economic theory as a tool to test and develop algorithmic models of the neural hardware for choice. This interdisciplinary collaboration was established by a set of meetings a conferences that started to take place. The first one took place in 1997 at Carnegie-Mellon University, organized by the economists Colin Camerer and George Loewenstein. (Glimcher and Fehr 2014: xxiii, Rinaldi 2009: 823)

2.3 Main Goals of Neuroeconomics

The purpose of neuroeconomics is not to overthrow previous theories but to reinforce or modify them; even to create a new unified theory. However, at present there are major differences between neuroscientists' and economists' approaches. The former, often tend to underestimate the complexity of the decision-making process, and thus they do not benefit from the existing knowledge, whereas the later consider neuroscience to be poorly connected with financial behavior and also too simplistic to explain such a complex model as decision making. (Glimcher et al. 2005:214) Furthermore, neuroscientists tend to typically focus on a single information processing task and a very limited range of neural regions. Economics, in contrast, has developed both analytical and simulation methods for modeling the coordination of diverse resources in pursuit of specific goals. (Loewestein 2008: 650)

According to Camerer (2013, 425), neuroeconomics has the same main goals with microeconomics. It focuses on understanding what causes choices, and the welfare properties of choice. The novel goal that is introduced by neuroeconomics is the attempt to link mathematical constructs and observable behavior to mechanistic details of neural circuitry. Several complementary methods are used.

Glimcher and Fehr (2014: 125) stated that neuroeconomics combines methods and theories from neuroscience, psychology, economics, and computer science and they try to answer three main questions: (i) what are the variables computed by the brain to make different types of decisions; (ii) how does the underlying neurobiology implement and constrain these computations; (iii) what are the implications of this knowledge for understanding behavior and well-being? Neuroeconomics attempt to create detailed computational and neurobiological models of the choice process that will also help the other natural and social sciences to understand human behavior.

In Camerer's words ((27)2008: 416):

> "the long-run goal of neuroeconomics is to create a theory of economic choice and exchange that is neutrally detailed, mathematically accurate, and behaviorally relevant".

2.4 The decision-making process according to neuroeconomics

According to neuroeconomists, the decision-making process is based on the following table (Table 1), which depicts the distinction that Schneider και Shiffrin (1977: 127) firstly proposed in 1977 between controlled and automated processes, and between cognition and affect. Many others have developed similar two-system models since then, with different labels, such as rule-based and associative, rational and experiential systems, reflective and reflexive, deliberative and implementive systems, assessment and locomotion, and type I and type II processes. (Camerer et al. 2005:15, Evans 2008: 256)

TABLE 1 TWO DIMENSIONS OF NEURAL FUNCTIONING		
	Cognitive	Affective
Controlled Processes ▪ serial ▪ effortful ▪ evoked deliberately ▪ good introspective access	I	II
Automatic Processes ▪ parallel ▪ effortless ▪ reflexive ▪ no introspective access	III	IV

Table 1. Source: Camerer et al. 2005:16.

2.4.1 Quadrant Analysis

The first quadrant represents processes which usually include matters of a mathematical nature, such as calculations of value or financial decisions. The second quadrant represents the rarest processes that occur in a rational act mainly because of their nature of the calculations it includes. The concept of imagination could fit in this category but we can only associate imagination with an agent who is daydreaming. It would be wrong to think that writing a report is part of the 2nd quarter since it is a fantasy product but it is also a conscious act, which is described by the 1st quarter. The third quadrant involves processes procedures that control our body movements, such as the movement of our hands or feet, or even it can be the conscious movement of handshake when someone greets us. The last quadrant includes processes such as those involved when something scares us and we suddenly jump up. Human behavior is the result of the interaction of all the three areas, with the last quadrat being dominant. (Camerer et al. 2005: 19-20)

2.4.2 Controlled Processes

Controlled decision-making processes, as described in the first row of the Table, are intentionally recalled by the agent when he needs to face a challenge, or solve a problem or exercise. For example, if someone is asked to solve a mathematical problem or choose between goods then he recalled thoughts, which are a step-by-step reasoning, until he reaches the final decision. Financial tools such as decision trees and dynamic programming can fit into this category. (Camerer et al. 2005: 16)

2.4.3 Automatic Processes

Automatic decision-making processes, on the other hand, are not subjected to control by consciousness and do not require thinking. As a result, people often have surprisingly little introspective insight into why automatic choices or judgments were made. In this processes, parallelism is also a key factor that facilitates rapid response and allows for massive multitasking. This makes their recollection time to be minimum. For instance, the recognition of colors and objects is an activity that fall into this category. The characterization of a person as "frivolous" or "sarcastic" is based on various data that we have in our minds. Later, in the event of a reconsideration we may form a different opinion on the same person, but this will no longer be effortless, it will be the result of further processing, something that belongs to the previous category. (Camerer et al. 2005: 16-17)

Furthermore, automatic processes are involved in automatic decisions, routine, and they also integrate the emotional dimension. (Corcos and Pannequin 2011: 17) Automatic processes are also fast, and efficient and highly specialized for domain-specific operations and therefore relatively inflexible. (Sanfey et al. 2006: 111)

2.4.4 Cognitive Processes

The second distinction, represented by the two columns of Table 1, is between affective and cognitive processes. Cognitive processes are the ones that answer true/false questions. According to Camerer and collegues (2005: 18), cognition cannot produce action by itself, but only through the operation via the affective system it can influence behavior.

Cognitive processes are also more deliberate and based on rationality. (Corcos and Pannequin 2011: 17) They are characterized by high flexibility, and are thus able to support a wide variety of goals, such as making trade-offs, behavior guided by anticipation of a reward, exploring/exploiting various possible outcomes. These procedures are also relatively slow and rely on limited capacity mechanisms, which makes them able to support only a small number of pursuits at a time. (Sanfey et al. 2006: 111)

2.4.5 Affective Processes

On the contrary, our behavior is strongly influenced by affective processes. Although most people associate affect with emotion, most of these procedures operate below the threshold of conscious awareness. These processes answer to “go/no-go” questions that motivate approach or avoidance behavior. Also, all affects have “valence”, which means they are either positive or negative, and they also carry “action tendencies”. Some examples of affective processes are when we are motivated by fear to escape or freeze, or by pain to take steps in order to ease the pain, or when anger makes us aggressive. Affect moreover involves drive states such as thirst, hunger and sexual desire, and motivational states such as discomfort, physical pain and drug craving. Affective systems play an important role in human motivation and thus, when they are damaged or perturbed due to brain injury, stress, imbalances in neurotransmitters, or the "heat of the moment," the logical-deliberative system-even if completely intact-cannot regulate behavior appropriately. (Camerer et al. 2005: 11, 18)

2.4.6 The Conflict between Emotion and Reason

Decision-making remains strongly influenced by the conflict between automatic and controlled processes. This dichotomy in decision-making processes notably suggests the approach of Kahneman and Frederick (Kahneman and Frederick 2002: 51), who distinguish between a System 1 and a System 2. System 1 is involved in automatic and emotional decisions, it quickly proposes intuitive answers to arising problems. Also, System 1 processes are believed rapidly contextualize problems with prior knowledge and belief. System 2 is more deliberative, it corresponds closely with controlled processes. It is thought to be associated with language, reflective consciousness, and higher-order control and with the capacity to think hypothetically about future and counterfactual possibilities. Additionally, System 2 monitors the quality of the answer provided by System 1 and sometimes corrects or overrides these judgments. (Evans 2008: 256, 259-61, Kahneman, 2003: 698-699, Sanfey et al. 2006: 111)

While these two systems interact with each other and share the same neural substrates, neuroimaging studies have suggested that these two systems may have distinct neural correlates and thus be parts of very different areas of the brain. (Corcos and Pannequin, 2011: 18) According to Lieberman (2002), automatic and controlled processes can be roughly distinguished in terms of what happens in brain. (Camerer et al. 2005: 16).

As depicted in Figure 1 (Camerer et al. 2005: 17), the back (occipital), top (parietal) and side (temporal) areas of the brain are the ones responsible for cognitive automatic activity. Important automatic reactions, for example fear, are mainly controlled from an area below the cortex called “amygdala”.

On the other hand, controlled reactions occur mainly in the front parts of the brain (orbital and prefrontal). (Camerer et al. 2005: 16). According to Shallice and Burgess (1996), the frontal cortex (pFC) sometimes it is called the "executive" region, because it is associated with almost all other areas, it is responsible for the formation of near and long-term goals, and it plans actions related to those goals (Camerer et al. 2005: 17).

It is important to state that there are several scientists who argue that the automatic and controlled systems should not be perceived as antagonistic but rather as cooperating. For instance, according to Sanfey and colleagues (2006:112, 2008) the systems for the most part work cooperatively, but sometimes compete. Corcos and Pannequin (2011: 17-19) described that there are numerous research articles studying the trade-off that occurs between the reward/punishment circuits and the deliberative circuit. It is evident from these articles that there is a causal link between choice and the relative level of activity of the two zones. In purchasing decisions, several experiments involving similar products but different brands, lead us to believe that both neural systems cooperate to produce subjects' preferences. The neural systems are activated differently when tradeoffs are made between immediate and deferred rewards. The limbic system is activated in the case of immediate rewards, whereas the lateral prefrontal cortex and posterior parietal cortex are generally focused on intertemporal trade-offs.

At the same time, Corcos and Pannequin (2011: 26) argue that there even might be a continuum of systems that lies between the automatic and controlled systems. Accordingly, Sanfey and colleagues (2006: 111) agree that it is probably best thought of the two systems as a continuum, rather than a qualitative dichotomy. Nevertheless, it has proven extremely useful in characterizing the dynamics of behavior involving competing processes. Similarly, Camerer and collegues (2005: 29) state that psychiatry recognizes a decision-making continuum defined by the impulsive, "light" decision-making style at one end and the compulsive, "heavy" style at the other.

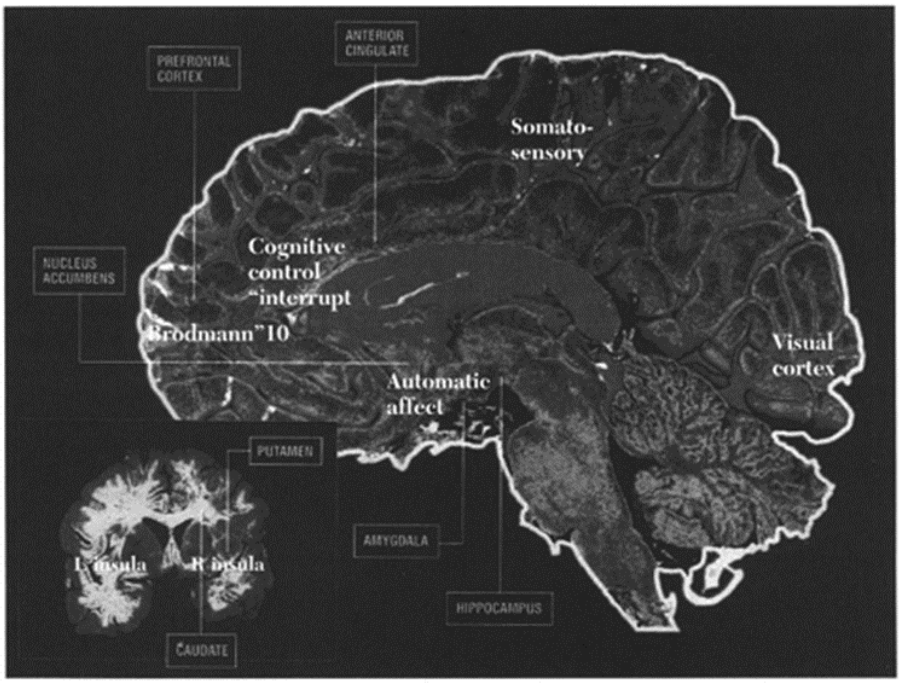

Figure 1. The human brain with some economically relevant areas marked.

Figure 1. Source: Camerer et al. 2005: 17.

The extent of collaboration and competition between cognitive and affective systems, and the outcome of conflict when it occurs, depends critically on the intensity of affect. When there are low levels of intensity, affect seems to play a largely "advisory" role. Intermediate levels of intensity make people conscious of conflicts between cognitive and affective inputs. Finally, at even greater levels of intensity affect can be so powerful as to virtually preclude decision making. These levels of intensity lead people to actions in which they report themselves as being "out of control" or "acting against their own self-interest". (Camerer et al. 2005: 30-31)

2.5 Brain Structure

The human brain is basically a mammalian brain with a larger cortex. This means that human behavior is a compound of evolved animal emptions and instincts and evolved human deliberation and foresight. This is an indication that we can learn a lot from studying primates, with whom we share 98% of our genes, and other animals. (Camerer et al. 2004: 558-559, Zeki et al. 2004: 1738)

Our brains consist of approximately 10^{11} neurons. The average neuron receives, on its dendrites, inputs from hundreds of other neurons and in turn makes synaptic contacts at its nerve endings with hundreds of other neurons. Also, a single human brain is estimated to have about 10^{15} synapses. Neurons from different areas are interconnected, which enables the brain to respond to complex stimuli in an integrated way. More specifically, neurons engaged in related computations tend to be grouped closely together, and communication between distant groups of neurons tends to employ highly efficient coding schemes employing a minimum number of axons. (Camerer et al. 2004: 559, Glimcher 2014: 68)

Broadly speaking the primate, and hence human, brain can be divided into three main divisions, which are, front to back, the telencephalon, or forebrain, the mesencephalon, or midbrain, and the brainstem or hindbrain. Lastly, the brainstem, which includes the pons and medulla, plays many critical roles in functions ranging from movement generation to breathing but is almost entirely outside the focus of neuroeconomic research today. A final area, the cerebellum, lies outside the brainstem and is principally involved in movement control. (Glimcher 2014: 68-69)

The telencephalon can be divided into three main areas, the cerebral cortex, the basal ganglia, and the thalamus. The basal ganglia is the more evolutionarily ancient structure, which is possessed in some form by all vertebrates. On the contrary, the cerebral cortex is a much more recently evolved structure. An important area of the basal ganglia is the dopaminergic system. The dopaminergic neurons receive projections from the output nuclei of the basal ganglia as well as from many other areas and project both to the frontal cortex and the input nuclei of the basal ganglia where their axon terminals release the neurotransmitter dopamine. The dopamine neurons have been of particular interest because there is now overwhelming evidence that these neurons encode a reward prediction error signal appropriate for error-correction based learning. (Glimcher 2014: 68-70)

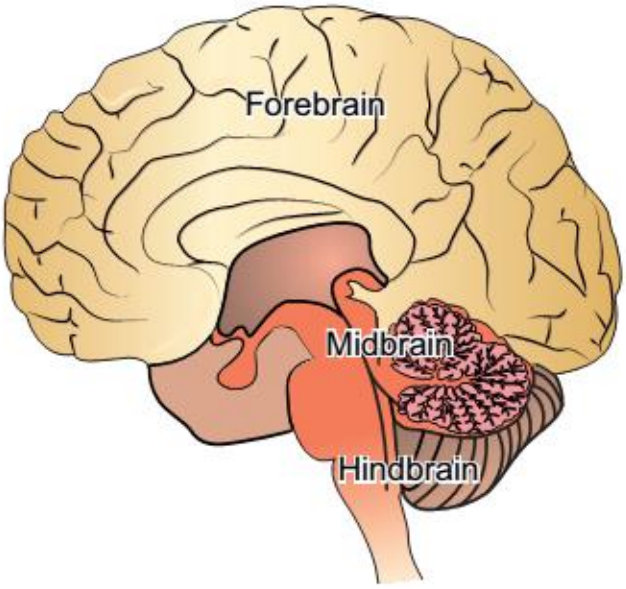

Figure 2. Main divisions of the human brain. Source: Glimcher 2014: 68.

The cerebral cortex is much larger than the basal ganglia in most primate species, consists of six layers, and is homogenous in structure. It performs a limited set of processing operations locally and then passes these mathematically transformed signals to other places, typically other places in the cortex. The cerebral cortex is a folded sheet that has been crumpled up to fit inside the skull. It is composed largely of cell bodies, which is referred to as grey matter. Beneath it there are dense runs of axons for interconnections between different places in the cortex, which are referred to as white matter. (Glimcher 2014: 69-70)

For hundreds of years the cerebral cortex has been divided into four to five main subdivisions, or lobes, that provide the first-order nomenclature for these systems. There are four lobes, the frontal, the parietal, the occipital and the temporal. Until recently the insula was considered an independent fifth lobe, although it is now often referred to as part of the frontal lobe. The frontal lobe is thought to be the center of cognitive control, planning and integration of cross-brain input. The parietal lobe is responsible for motor action, whereas the occipital lobe is where the visual processing occurs. Finally, the temporal lobes are important for memory, emotion and recognition. (Camerer et al. 2004: 558-559, Glimcher 2014: 70, Zeki et al., 2004: 1739)

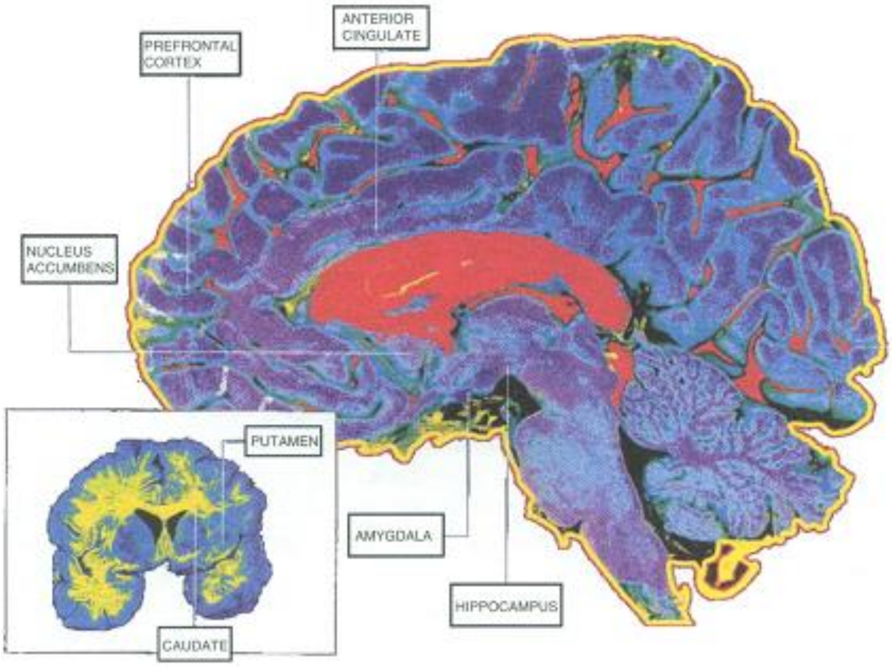

Figure 3. Human brain (frontal pole left) regions of potential interest to economists. Source: Camerer et al. 2004: 559.

Two final areas that deserve to be mentioned are the amygdala and the hippocampus. The amygdala is a portion of the telencephalon that is not classically considered part of the cerebral cortex or the basal ganglia. The amygdala is of particular interest because several studies now suggest that the psychological state of fear can be mapped to activation of the amygdala. Furthermore, according to Camerer (2013: 428), it rapidly encodes vigilance (e.g., fear of shock) and economic variables including ambiguity and loss. The hippocampus, on the other hand, lies adjacent to the amygdala and is a three-layered cortex-like structure that is widely believed to be the evolutionary progenitor of the cerebral cortex. The hippocampus plays a critical role in the formation of several classes of long-term memory and it is studied in neuroscientific studies of learning and memory. (Glimcher 2014: 70-71)

2.6 Neuroeconomics Research Tools

Neuroeconomics experiments provide evidence on the biological basis of human decision making. There are different types of neuroeconomic experiments, including: (i) purely "behavioral" experiments with healthy volunteers that provide evidence on the role of, for example, emotion on decision; (ii) "lesion" studies that examine the behavioral consequences of brain damage (or temporary disruption with transcranial magnetic stimulation (TMS); (iii) examinations of drug effects on economic decisions; (iv) skull-based measurement of brain electrical activity during decision tasks using electroencephalography (EEG) or magnetoencephalography (MEG); and (v) real-time whole brain imaging using functional magnetic resonance imaging (fMRI) during an economic decision task. (Glimcher and Fehr, 2014: 28-29)

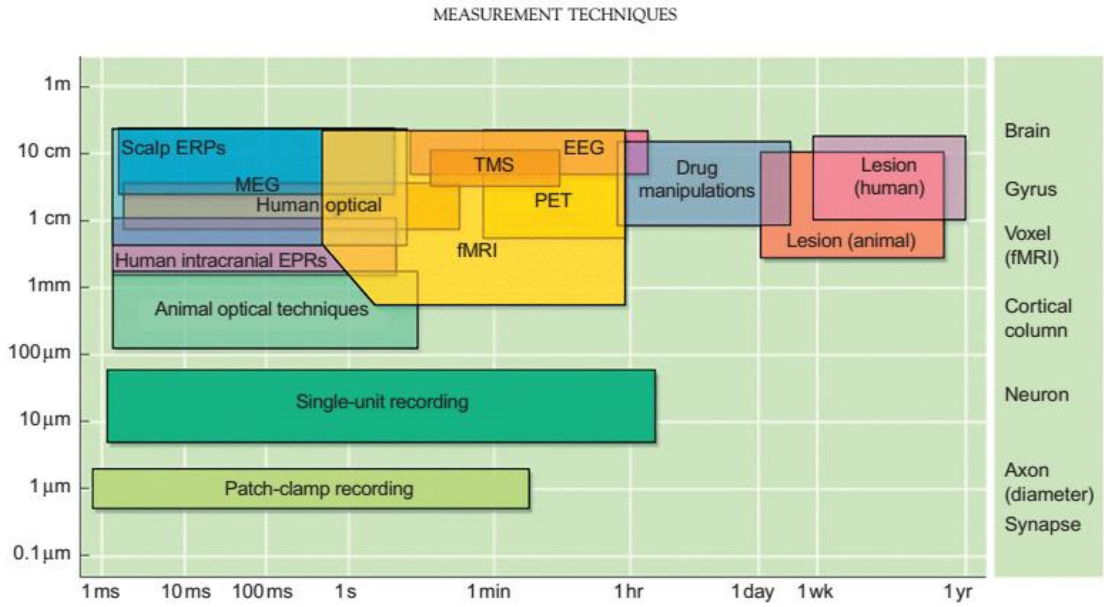

Table 2. Neuroscience techniques differ in their spatial and temporal resolution. The vertical axes illustrate spatial resolution in terms of distance (left) and the corresponding brain structures (right). The horizontal axis illustrates temporal resolution. This graph includes the most common techniques used in current cognitive neuroscience research. Techniques that involve data collection from human participants tend to operate at relatively coarser spatial scales than those that record from non-human animals. Electrophysiological techniques that provide excellent temporal resolution in human participants (e.g., scalp ERPs) have the disadvantage of relatively low spatial resolution as compared to neuroimaging techniques (e.g., fMRI). Because of the differing strengths and limitations of each technique, cognitive neuroscience research often applies a range of techniques to a single experimental question. ERPs, event-related potentials; MEG, magnetoencephalography; TMS, transcranial magnetic stimulation; EEG, electroencephalography; PET, positron emission tomography. Figure and caption adapted from Glimcher and Fehr, 2014: 79.

2.6.1 Functional Magnetic Resonance Imaging (fMRI)

The newest, and currently most popular, imaging method is functional magnetic resonance imaging (fMRI). fMRI was first used on humans in 1992, and produces 3D renderings of regional neural activity. Participants in fMRI experiments must sit inside a big circular machine that produces the magnetic fields and remain very still. Neural activity, however, is not directly measured. It uses a magnetic field to measure the oxygen content of blood. Rather, one obtains evidence on cerebral blood flow, which has long been understood to be tightly connected to underlying neuronal activations. The brain's neurons consume oxygen when active. This leads its surrounding capillary bed to dilate and (with some delay) increases the level of oxygenated blood, as well as the overall volume of blood, in the area of neural activity. It turns out that this hemodynamic response to neural activity can be detected and tracked over time and (brain) space. Unfortunately, the signal detected by the fMRI is weak, so drawing inferences requires repeated sampling and many trials. The data obtained by fMRI are BOLD signals that indirectly measure regional neural and synaptic activity by examining the amount of oxygenated to deoxygenated blood (the haemodynamic response).

Therefore, one can detect variation in the blood oxygenation level-dependent (BOLD) signal in real time and draw inferences regarding the relatively more and less active parts of the brain. An fMRI machine can plot the brain's activity (the BOLD signal) on a map of approximately 25,000 3 mm cubes. This is often visualized as a cross-sectional picture of a brain with "brain blobs" indicating the areas that are relatively more active at that point in the decision task.Therefore, it is assumed that the fMRI images faithfully represent regional changes in neural activity which are apparent when a contrast is highlighted between regions that are rich in oxyhemoglobin, that is when blood flow is increased, and regions that exhibit normal blood flow. (Aimone et al., 2016: 653, Camerer et al. 2004: 557, Camerer et al. 2005: 12, Graziano, 2013: 30, Houser and McCabe, 2014:29, Zeki et al., 2004: 1739-1740).

fMRI has emerged as the dominant technique because it is a relatively easily implemented, non-invasive procedure that allows scientific inference with respect to real-time brain function in healthy volunteers during decision tasks. (Houser and McCabe, 2014: 29) Although fMRI provides good locational accuracy in measuring neural activity during decision making, the temporal resolution of fMRI is slow (several seconds), and it is the method with the highest marginal cost per data point. (Camerer, 2013: 4) It takes about 2 seconds to measure "current" activity in brain. Although this can provide a time course of neural activity, measurement occurs much more slowly than the brain processes information. Many neural processes that interest researchers relate to decisions made rapidly or reflexively, such as judgments of risk and value, or a Wall Street stock trader's adjustments to price changes. As a result, many valuable data remains undetected. This highlights the importance of complementing fMRI techniques with additional tools and, fortunately, technology is improving rapidly. To date, fMRI technology has reached a high level of sophistication, and powerful analysis packages exist facilitating, to some extent standardized approaches to neuroimaging. (Aimone et al., 2016: 654, Braeutigam, 2012: 12, Camerer et al. 2004: 558, Farb, 2013: 8)

An example of an fMRI neuroeconomics experiment investigated the neural basis of economic decision-making in the ultimatum game. The fMRI data obtained in that study, by Sanfey et al., suggest that unfair offers activate both anterior insula and dorsolateral prefrontal cortices associated with emotion and cognition, respectively. Moreover, activity in anterior insula is significantly increased for rejected unfair offers, suggesting a key role for emotion in choice and decision-making. (Braeutigam 2005: 356)

2.6.2 Electroencephalography (EEG)

Electroencephalography (EEG) is an alternative neural measurement tool and perhaps the oldest of all noninvasive electrophysiologic recording techniques, used for the first time in the late 1920s. (Aimone and Houser, 2016: 654, Braeutigam, 2012: 12) According to Sundararajan and colleagues (2017: 2), EEG data have been used to predict purchase decisions, consumer's future choices, and preferences and responses to advertisements.

It is the only method used with humans that directly monitors neural activity, recording the electrical activity of the brain directly in the scalp. It uses scale electrodes attached to the scalp to measure electrical activity synchronized to stimulus events or behavioral responses (known as Event Related Potentials or ERP). (Camerer et al. 2005: 12, Sundararajan et al., 2017: 10) EEG thus takes advantage of the direct electrical properties of neural activity. Neurons communicate with each other through electrical currents and ssimultaneous systematic communication between many neurons rises the electrical potential to a point at which it can be measured by electrodes placed on a person's scalp. (Aimone and Houser, 2016: 654) EEG records timing of electrical activity from outer brain areas very rapidly and precisely (~ 1 millisecond). Sometimes it can also be used to interpolate activity in areas deeper in the brain. (Camerer 2007: C30, Camerer et al. 2004: 557)

EEG signals have high temporal resolution, thus providing rich time series data of brain activity, which allows researchers to compose a quantitative map showing areas of the brain where neural activity occurs at that point in time and create models of ongoing dynamic processing. (Aimone and Houser, 2016: 654, Ruff and Huettel, 2014: 82) However, because the EEG signal is affected to a larger degree by tissue and skull inhomogeneities, thus spatial resolution is poor, which means EEG is relatively imprecise regarding the location within the brain where that activity occurs. Brain data is inherently noisy, because it captures the brain activity for the stimuli, along with other activity unrelated to the task of the experiment. In order to overcome this problem, neuroeconomic experiments typically aggregate data from hundreds of trials from each participant. Apart from that, EEG is a less expensive method, which makes EEG systems are popular choices for institutions to obtain brain data, making it more accessible. It has also become a primary technique for commercial applications of neuroscience research, such as neuromarketing. For economics, a major advantage of EEG is its relative unobtrusiveness and portability. (Aimone and Houser, 2016: 655, Braeutigam, 2012: 12, Camerer et al. 2004: 557, Camerer et al. 2005: 12, Ruff and Huettel 2014: 82-83, Sundararajan et al., 2017: 10)

Gehring and Willoughby have used electroencephalography (EEG) to study neuronal response in subjects performing a simple monetary gambling task, where participant's choices are followed by outcome stimuli that inform about gains and losses. The main finding in that study is an outcome-related evoked component, most likely generated in medial-frontal brain regions. Crucially, this component is greater in amplitude when a subject's choice results in a loss than when it results in a gain. Furthermore, choices made after losses are riskier and are associated with stronger loss-related activity than choices made after gains. Those results suggest that neuronal processes in medial-frontal brain areas may relate to mental processes involved in economic decisions. Gehring and Willoughby's observations may also contribute to a better understanding of how individual choices deviate from normative behavior, according to which the context in which a choice occurs – here the sequence of gains and losses– should not affect the choice. (Braeutigam 2005: 355-356)

2.6.3 Positron Emission Tomography (PET)

Positron Emission Tomography (PET) was the first neuroimaging technique to gain widespread acceptance, rapidly changing time-frame of neuroscience. It can be conducted in human volunteer participants, human patients, and non-human animals. It is an invasive technique, as it measures blood flow in the brain, which is an indicator of neural activity, after a weakly radioactive blood injection**.** (Camerer et al. 2005: 12, Ruff and Huettel, 2014: 86)

Researchers inject a quantity of a radioactive isotope itself attached to a metabolically relevant molecule like glucose or to a neurotransmitter that binds to a particular type of neuron into the venous system of a participant. Depending on the nature of ongoing brain metabolism, that isotope will be differentially distributed throughout the brain. As the isotope decays, it emits radioactive particles, positrons, which travel through the brain until they encounter an electron (on average, within a few millimeters); that collision annihilates both particles and releases two gamma rays that travel in opposite directions away from the impact site. By detecting the coincident arrival of gamma rays in detectors around the head, the PET scanner can compute the likely location at which the positron was emitted. If the brain is monitored for an extended period of time (typically minutes), enough of these emission events will accumulate to allow analysis software to estimate the rough distribution of the isotope throughout the brain. That distribution, when converted to a statistical map, becomes a PET image. (Ruff and Huettel, 2014: 85-86)

PET can provide very precise chemical information about different aspects of neural metabolism or neurotransmission. It also PET gives better spatial resolution than EEG, but poorer temporal resolution and is limited to short tasks (because the radioactivity decays rapidly). For most studies, data is aggregated over an entire experimental condition, collapsed over the different parts of a complex task. However, PET usually requires averaging over fewer trials than fMRI. Additionaly, due to the involvement of a radioactive material in the procedure, safety guidelines restrict how that radioactive material can be created, handled, and administered, making PET studies much more logistically complex than the other techniques. (Camerer, 2007: C30, Camerer et al. 2004: 557, Ruff and Huettel, 2014: 86-87)

Smith et al. have used positron emission tomography (PET) to study neuronal responses in subjects choosing between risky games (known payoffs with well-defined probabilities) and ambiguous games (known payoffs with undefined probabilities). The main finding in that study is a behavioral interaction effect between outcome structure (risk/ambiguity) and payoff structure (loss/gain). This effect maps onto two different neuronal pathways: a dorsomedial neocortical and a ventromedial system. Interestingly, the interaction effect observed in that study is contrary to standard economic reasoning, where one assumes the evaluations of outcomes and payoffs to be independent. Thus, the results obtained by Smith et al. may further contribute to a better understanding of how individual behavior deviates from normative predictions. (Braeutigam 2005: 356)

2.6.4 Transcranial Magnetic Tomography (TMS)

Transcranial Magnetic Tomography (TMS) is a relatively new method which uses pulsed magnetic fields to temporarily disrupt brain function in specific regions and thus allows researchers either to block or artificially stimulate a region of the brain. It can be used on almost any healthy volunteer who meets a few basic health-related criteria, such as absence of proneness to epilepsy and of previous brain damage or brain illness. During a TMS experiment, an electromagnetic looped copper coil is placed against the part of the scalp overlying the area of the brain that will be stimulated or suppressed by running a strong, rapidly changing electrical current through the coil. This electric current acts on the underlying neurons and triggers action potentials and thus TMS can provide researchers with greater ability to identify the causal role that different areas of the brain play in various economic decisions. (Aimone and Houser, 2016: 654, Camerer et al. 2005: 13, Ruff and Huettel, 2014: 93, 95)

The theoretical advantage of TMS is that it directly leads to causal inferences about brain functioning. Unfortunately, the use of TMS is currently limited to the cortex. [6] The observation of similar or different behavior between groups of people (e.g., subjects with either natural or artificial lesions) can help to illustrate whether the regions identified by fMRI, EEG, or TMS studies are necessary regions for certain decision processes. TMS can also be used in conjunction with imaging tools. TMS allows non-invasive manipulation of neural processing with high spatial resolution (about one centimeter) and exceptional temporal resolution (milliseconds). Because TMS can temporarily change a person's brain function, it is considered more invasive than fMRI or EEG. However, it is considered controversial because it might cause seizures or other long-run effects. (Aimone and Houser 2016: 655, Camerer et al. 2005: 14, Ruff and Huettel 2014: 93, 95)

Knoch et al. (2006) used TMS to disrupt/reduce activation in the right or left dorsolateral prefrontal cortex (DLPFC) in order to test whether an increasing DLPFC activation is acting in a causal channel leading one to reject unfair ultimatum game offers, thus fundamentally overriding selfish monetary maximization. (Aimone and Houser 2016: 654-655)

2.6.5 Magnetoencephalography (MEG)

Electrical currents, like those generated by dendritic activity of neurons, also give rise to magnetic fields and thus to neuroimaging methods such as Magnetoencephalography (MEG). MEG is based on the detection of the magnetic fields that are generated by the currents flowing in neurons, using specialized electrical coils called superconducting quantum interference devices, or SQUIDs. These coils operate at cryogenic temperature which means that when they are cooled to very low temperatures, these coils become superconductors that are extraordinarily sensitive to changes in magnetic field. MEG is preferentially sensitive

[6] It is particularly useful for studying visual processes in the occipital lobe, in the back of the head.

to magnetic fields generated in the cerebral cortex. However, with the arrangement of many SQUIDs, often several hundred, in a large helmet-like device that surrounds the participant's head, researchers can even detect activity in subcortical regions. (Braeutigam, 2012: 12, Ruff and Huettel, 2014: 83)

MEG provides many advantages for cognitive neuroscience research. It is a non-invasive method, which can record data from the entire brain simultaneously, providing insight into the combined location and timing of cortical activity with great precision. Moreover, MEG detectors are sensitive to field changes occurring over timescales of milliseconds to seconds, thus complementing fMRI, which is sensitive to longer-term changes. MEG can also be used with a wide range of experimental paradigms. However, there are also some drawbacks, such as the fact that this method is quite inaccessible due to very high costs of purchasing and maintenance. MEG also has better source localization than EEG, partially because magnetic fields more readily pass through the skull and scalp. However, MEG data have some limits in their spatial sensitivity and, at the same time, researchers face the problem that they cannot unambiguously identify the generating neural sources from a MEG recording. (Braeutigam, 2012: 12, Ruff and Huettel, 2014: 84)

2.6.6 Transcranial Direct Current Stimulation (tDCS)

Transcranial Direct Current Stimulation (tDCS) involves the attachement of two electrodes to the scalp and the application of a week but constant electric current between them. The first step of a tDCS experiment involves the attachment of the active electrode to the area where we want to stimulate the target site, and the attachment of the reference electrode to the area that is not of interest in a given study. Due to the electric stimulation, the membrane voltage of the neurons along the path of the current slightly changes and they spontaneously fire. These effects are increased directly beneath the positively (anode) charged electrode but decreased under the negatively (cathode) charged electrode. (Ruff and Huettel, 2014:96-97)

2.6.7 Single-neuron measurement

The previous techniques only measure activity of "circuits" consisting of thousands neuros. In single neuron measurement, tiny electrodes are inserted into the brain and measure the firing of a specific single neuron. A limitation of single-neuron measurement is that, due to the damage it causes to neurons, this method is only used on animals and special human populations (in order to locate the source of epileptic convulsions). Due to the use only on animals, this technique has produced more data about basic emotional and motivational processes than about higher-level processes such as language and consciousness. However, studying animals is informative for humans because many brain structure functions of non-human mammals are similar to those of humans. (Camerer et al. 2004: 558, Camerer et al. 2005: 12-13)

2.6.8 Electrical Brain Stimulation (EBS)

Similarly to the previous method, electrical brain stimulation (EBS) is another method that is largely restricted to animals. In 1954, two psychologists (James Olds and Peter Milner 1954) experimented on rats and discovered that they would learn and execute novel behaviors if rewarded by brief pulses of electrical brain stimulation (EBS) to certain sites in the brain. Rats (and even humans) will work hard for a big series of EBS pulses; they will leap over hurdles, cross electrified grids, and forego their only daily opportunities to eat, drink, or mate. Animals also trade EBS off against smaller rewards in a sensible fashion, for instance, when hungry they demand bigger amount of EBS in order to forego food. Unlike more naturalistic rewards, EBS does not satiate. In addition, when electrical stimulation occurs at specific areas it often elicits behaviors such as eating, drinking, or copulation. Also, when under the influence of drugs, such as cocaine, amphetamine, heroin, cannabis, and nicotine, animals have lower threshold at which they will lever-press for EBS. Although EBS has obvious applications to economics, only a few experiments about the substitutability of EBS have been conducted. (Camerer et al. 2005: 13)

2.7 Psychopathology and Brain Damage in Humans

Studies that systematically investigated the correlation between behavior and brain damage were the first and most striking demonstrations that brain function affects behavior. This practice is often referred to as neuropsychology, originated in the neurological clinic in the 19th and 20th centuries. Patients who have undergone neurosurgical procedures such as lobotomy (used in the past to treat depression) or radical bisection of the brain (an extreme remedy for epilepsy, now rarely used), degenerative diseases of the nervous system (e.g., Parkinson's Disease (PD)), chronic mental illnesses (e.g., schizophrenia), and developmental disorders (e.g., autism) shed a light on the mechanisms of our brain. Most forms of illness have been associated with specific brain areas and in some cases. Generally, when there is a known known damage to an area X of the patient’s brain and the patient performs a special task more poorly than a "normal" patient, and does other tasks equally well, we can assume that area X is used to do the special task. Also, the progression of illness has a localized path in the brain. For example, PD initially affects the basal ganglia and later spreads to the cortex and thus, early symptoms of PD provide clues about the specific role of basal ganglia in brain functioning. (Camerer et al. 2004: 558, Camerer et al. 2005: 13, Ruff and Huettel 2014: 101-102)

To test a hypothesis about the functional role of a given brain area using the lesion approach, researchers first identify a group of patients with more or less selective damage to that brain area. Then researchers try to reconstruct the full extent and overlap of the lesions, ideally using MRI and possibly functional measures of brain activity. Next, it is necessary to identify a suitable control group, which needs to be closely matched to the patients, for behavioral comparison. Then, in most studies, a series of tasks designed to isolate specific components of cognition or behavior are conducted in order to measure and compare the behavioral performance of the two groups. (Ruff and Huettel 2014: 101)

An advantage of this research method is that severe damages may provide much stronger support for the behavioral necessity of a brain area than the subtler changes in task performance found in brain stimulation studies. Furthermore, the behavioral deficits are a result of naturally occurring illnesses and accidents and thus, can lead to new hypothesis about the correlation between brain and behavior that might not have been considered in other circumstances. This method is also always relevant for medical care and may help the diagnosis and treatment of these disorders. (Ruff and Huettel 2014: 102)

However there are also some disadvantages of the lesion approach, such as the fact that naturally occurring brain damage is often spatially diffuse and seldom selective to specific brain areas, making it very difficult to find patients with similar damage in the areas of interest. Additionaly, because brain lesions are constant and usually irreversible, lesion studies offer no information about the timing of neural activity. Finally, brain injuries and illnesses and their treatment can have nonspecific sequelae that may affect behavior, such as brain reorganization, medication effects, or an altered life situation. (Ruff and Huettel 2014: 103)

An example of a patient with a lesion that gave important insights about the relationship between brain damage and behavior is patient "S.M." who has bilateral amygdala damage. She can recognize all facial expressions except fear; and she does not perceive faces as untrustworthy the way others do. This is powerful evidence that the human amygdala is crucial for judging who is afraid and who to distrust. (Camerer et al 2004: 558)

2.8 Chemical Manipulations

Chemicals and medicines were used extensively in the 20th century to modify behavior and study the mechanisms by which these substances work. Some of these substances, such as caffeine and marijuana, are not normally present in the body and artificially change the way the brain functions, whereas others, such as the neuropeptide oxytocin and the hormone cortisol, are naturally occurring in the body but can be artificially manipulated. Recently, there have been many studies exploring how economic decisions are governed or impacted by the body’s levels of these substances. Most of these researches have a behavioral design, where exogenous treatments either increase or decrease the levels of these substances. (Aimone and Houser 2016: 656)

2.8.1 Oxytocin

Many neuroeconomic studies investigate why healthy individuals fail to trust. There have been various experiments that involve exogenous manipulation of the neuropeptide oxytocin, which has surfaced as an intriguing player in the brain's decision whether to trust. There have been various experiments which indicate that oxytocin is a powerful hormone in social bonding, as it influences pair-bonding and is critical for infant–parent bonding. The importance of oxytocin in social behavior became evident in the 1990s with Insel and Young's work on pair-bonding in two closely related species of voles. (Aimone and Houser 2016: 661, Busemeyer and Diederich: 271)

From then on, different experiments have been conducted on human subjects, including direct measurement from blood samples suggesting that oxytocin is important in trust. Zak et al.'s experiment in 2005 showed a rise of oxytocin levels when individuals are intentionally shown trust via monetary transfers. Indeed, those with higher oxytocin levels showed increased monetary sacrifice. (Camerer 2007: C37, Morhenn et al. 2008: 375) Moreover, the role of hormones in trust games has been explored by Zak earlier, in 2003. In a canonical trust game, one player can invest up to $10.00, which is tripled. A second "trustee" player can either keep or repay as much of the tripled investment as they want. Zak et al. measured eight hormones at different points in the trust game and found out that the hormone with the largest effect was oxytocin, which rose in the trustee if the first player "trusts" her by investing a lot. (Camerer et al. 2004: 571-72, Camerer et al. 2005: 48)

Other oxytocin infusion studies, carried out by Kosfeld et al. (2005), and by Zak et al. (2007), suggested that oxytocin also affects general decision to trust. In the former study, the researchers suggested that oxytocin modulated betrayal aversion, the aversion to the negative emotions associated with discovery that one's trust was betrayed. This experiment showed that when oxytocin was administered intranasally, those with high levels of oxytocin in their body showed an increased willingness to trust (up to 17% more than the placebo group) but no increased expectations of reciprocation, no changes in tolerance for monetary risk, and no changes in willingness to betray trust. Thus, the researchers concluded that oxytocin's effect was that it reduced barriers to trust and particularly betrayal aversion, limiting the fear of betrayal in social interactions, rather than actually increasing trust. In the later study, Zak et al. demonstrated that generosity was raised by 80% due to oxytocin infusion. Similar studies have also presented evidence of strong effects of the neuropeptide in decision making. Domes et al., for example, showed in their study that elevated oxytocin levels improve the ability of participants to infer the mental states of other people. More recent studies, including oxytocin fMRI experiments by Baumgarter et al. (2008), and by Lauharatanahirun et al. (2012), have also supports the hypothesis that oxytocin reduces betrayal aversion via reducing amygdalar responses during trust games. (Aimone and Houser 2016: 660-661, Camerer 2007: C37-C38, Crockett and Fehr 2014: 272, Park and Zak 2007: 50)

2.8.2 Serotonin

Researchers have also been interested in the role of neurotransmitter serotonin in decision-making, which they believe is also significant. (Rinaldi 2009: 823) The initial experiments involved rodents on whom researchers used neurotoxin-induced global serotonin depletions. The result was that serotonin depletion led to impatient choices for small immediate rewards. Thus, serotonin plays a critical role on the ability to wait for delayed rewards. Several other studies led to the same evidence, this time using alternative methods for manipulating serotonin function. (Crockett and Fehr 2014: 265)

In human subjects, the influence of serotonin on intertemporal choice has been studied using acute tryptophan depletion (ATD), a dietary precursor manipulation that results in a transient global reduction of brain serotonin. A study by Schweighofer et al. concluded that choices for smaller but sooner rewards were increased due to ATD, without affecting learning or choice variability. Another study, by Tanaka et al., using an fMRI and the same task, showed that ATD also increases impatient choice by enhancing activity in the ventral striatum[7] during short-term reward prediction. In the same study, augmenting serotonin function with tryptophan supplementation enhanced activity in the dorsal striatum[8] during long-term reward prediction. Similar studies, have shown that the ability to tolerate delays before larger rewards can be undermined by depletions of serotonin. These findings provided evidence that serotonin modulates intertemporal choice through its actions in the striatum[9]. Thus, serotonin has profound effects on time preferences across species and its enhancement reduces impatient choice. (Crockett and Fehr 2014: 265-266, Rogers 2010: 121-122)

There have also been experiments linking serotonin with the bias of the 'framing effect'. For instance, Jonathan Roiser et al. (2009), investigated how economic decision-making is affected by two variants—the 'short' and 'long' alleles—of the serotonin transporter gene *5-HTTLPR* and how this correlates to the activity of the amygdala, an area of the brain implicated in processing emotions. They linked the individual's genetic make-up with the economic decision-making bias of 'framing effect'.[10] The concluded that the amygdala was more active during decisions where the frame influenced an individual's choice in carriers of the genotype more vulnerable to the bias, which suggested that the bias in the 'short/ short'

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[7] In primates, the striatum [information about the striatum can be found on footnote 9] is divided into a ventral striatum, and a dorsal striatum, subdivisions that are based upon function and connections. The ventral striatum consists of the nucleus accumbens and the olfactory tubercle.

[8] The dorsal striatum, along with the ventral striatum [information about the ventral striatum can be found on footnote 7] constitute the striatum [for information about the striatum see footnote 9]. The dorsal striatum consists of the caudate nucleus and the putamen.

[9] The striatum, or corpus striatum (also called the neostriatum and the striate nucleus) is a nucleus (a cluster of neurons) in the subcortical basal ganglia of the forebrain. The striatum is a critical component of the motor and reward systems; receives glutamatergic and dopaminergic inputs from different sources; and serves as the primary input to the rest of the basal ganglia. Functionally, the striatum coordinates multiple aspects of cognition, including both motor and action planning, decision-making, motivation, reinforcement, and reward perception

[10] The 'frame effect' occurs when the phrasing (or 'framing') of a decision affects an individual's eventual choice, even when the meaning of the decision is not changed. For example, a supermarket might advertise their yoghurt as '99% fat free' as opposed to '1% fat', though these two statements mean the same thing.

individuals may have been driven by automatic emotional responses to the framing of the question, over-riding analytic decision-making processes that take place in other areas of the brain. (Rinaldi 2009: 823-824)

At the same time, recent experiments with human subjects have shown that serotonin activity may also influence risky decisions, specifically those involving aspects of non-normative choice. However, Rogers (2010: 122-123) points out that although there has been a clinical association between altered serotonin function and risky behaviors, only a few experiments have examined the role of serotonin in risky choices associated with larger rewards. A recent experiment, conducted by Murphy et al. (2009), involved a 14 day of tryptophan supplements which enhanced serotonin activity, and reduced the reflection effect, manifested as shifts between risk-seeking choices (when confronted with certain losses and options associated with larger losses or no losses) and risk-avoidant choices (when confronted with certain gains and options associated with larger gains or no gains at all. In addition, tryptophan supplements increased choices of gambles with small negative expected values, raising the possibility that serotonin mediates aspects of loss aversion.

2.8.3 Dopamine

Dopamine is another neurotransmitter that influences decision-making behavior. For example, there have been clinical evidence which suggests that chronic substance misusers show significant impairments in the capacity to decide between probabilistic outcomes, reflecting possible disturbances of dopaminergic, and possibly serotonergic, modulation of fronto-striatal systems.

Dopamine is also related to decision-making under risk. For instance, in adult clinical populations, dopaminergic agents have appeared to improve decision making. Methylphenidate has reduced in comparison with single placebo treatments, has been shown to reduce the heightened tendency to take risks - manifested again as a tendency to wager more reward on previous choices being correct. (Rogers 2010: 116)

Moreover, one of the most important neuroeconomic discoveries, relating to the important role of the concept of reward, was the correlation between the neural structures named 'dopaminergic systems' and reward, motivation, evaluation and learning. Recent neuroscientific discoveries, by Schultz et al., have demonstrated the link between dopamine and learning through experience, in which the dopaminergic response is transferred from an unconditioned stimulus (the reward itself) to a conditioned stimulus (the reward announcer). The dopaminergic neurons, which initially are triggered by the arrival of the reward, therefore, are activated later particularly in light of the conditioned stimuli. (Graziano 2013: 35)

According to Homberg (Rogers 2010: 116-117), dopamine plays a critical role in predicting rewards in Pavlovian and instrumental forms of learning and, updating the value of actions on the basis of this learning. For example, experiments in humans conducted by

Schultz and colleagues, showed that unexpected rewards induce phasic increases in the activity of midbrain dopamine neurons, whereas the omission of expected rewards produce depressions in their activity, thus instantiating positive and negative prediction errors.

Chapter 3. Important Neuroeconomic Findings

Probably the most important and novel contribution of neuroeconomics is that it provides empirical evidence of how mental states influence choice, and it also describes the neural mechanisms of influences. Nowadays, there are multiple competing models about rationality and behavior of choices over risk, ambiguity, time, social interaction etc., in various domains and in different contexts. As Camerer stated (2013: 432-433), in some cases, two or more models can be interpreted as making different predictions about both choice patterns and underlying cognitive or neural mechanisms.

3.1 Risk and Uncertainty

There are many theories of choice under risk and uncertainty. Neuroeconomists investigate what computational and neural mechanisms in the brain are likely to implement these theories in order to produce interesting predictions and permit causal experiments. Thus, there are various neuroeconomic findings suggest that decision-making under risk and uncertainty is associated with key valuation structures of the brain, such as the striatum and medial prefrontal cortex. (Tobler and Weber 2014: 159) As Tobler and Weber (2014: 149) said, choice under risk and uncertainty is distinguished from other forms of decision making by the fact that they lead to different outcomes with different probabilities.

According to economist Frank Knight (1921) there is a conceptual difference between risk and uncertainty or ‘ambiguity’. Risk refers to situations where the decision maker knows with certainty the mathematical probabilities of possible outcomes of choice alternatives, whereas in uncertainty people are missing information about probabilities they would like to know but don't and thus the likelihood of different outcomes cannot be mathematically calculated. (Camerer et al. 2004: 568, Tobler and Weber 2014:150) There is neural evidence that substantiates this distinction. For example, subjects facing ambiguous gambles, often report a feeling of discomfort or mild fear (Camerer et al. 2005: 45) and their inferior frontal gyrus was activated. As Loewenstein and colleagues stated (2008: 656), it is evident that people appear to have an immediate negative emotional reaction to ambiguity. On the other hand, much aversion to risks is driven by immediate fear responses, which are largely traceable to the amygdala. (Camerer et al. 2004: 567) Also, neurons in posterior cingulate cortex (CGp) may be involved in risky decision making. (Platt and Huettel 2008: 402)

Furthermore, brain imaging shows that different degrees of risk and uncertainty activate different areas of the brain. Using fMRI, Hsu and Camerer (2004) found that the insula cortex was differentially activated when people chose certain money amounts rather than ambiguous gambles. This evidence suggests a neural basis for pessimism or "fear of the unknown" influencing choices. Also, Ming Hsu et al. (2005) found that activation in amygdala as well as orbitofrontal cortex[11] was significantly greater in the ambiguity condition than in the risk condition. They also found that patients with orbitofrontal cortical (OFC) lesions are ambiguity-neutral, compared to brain-damaged controls. Both fMRI and lesion evidence imply that in normal subjects, ambiguous gambles often create discomfort or fear which is transmitted to the OFC. Ironically, patients with OFC brain damage therefore behave more "rationally" than normal subjects, treating ambiguous and risky gambles similarly. (25) Camerer 2005: 45) (Loewenstein et al. 2008: 656)

Decision-making under risk and uncertainty also depicts both collaboration and competition between affect and cognition, and between controlled and automatic processes. (Camerer et al. 2005: 43) For instance, in a well-known study conducted by Bechara et al. (1997), the collaboration of the systems is evident. The subjects included patients suffering prefrontal damage and also normal subjects who had to choose a sequence of cards from four decks whose payoffs the subjects only learned from experience. Two decks had more cards with extreme wins and losses and thus negative expected value, whereas the other two had less extreme outcomes but positive expected value. Both groups exhibited similar immediate emotional reaction based on their skin conductance; both groups started sweating, which is an indication of fear, after encountering large loss cards. However, compared to normal subjects, damaged subjects rapidly returned to the high-paying risky decks after suffering a loss and, as a result, went "bankrupt" more often. This finding indicated that damaged patients do not store the pain of remembered losses as well as normal subjects, so their skin conductance rose much less than normal subjects' when they resampled the high risk decks. In fact, even among normal subjects, those who were lowest in emotional reactivity acted more like the prefrontal patients. (Camerer 2005: 44, Camerer et al. 2004: 568-569)

3.2 Reward

As Zeki and collegues stated (2004: 1740), all animals need to obtain resources to survive, and the neural structures needed for reward acquisition are primitive and well conserved across species. Choice execution is preceded by the evaluation of the reward associated with each choice, but the evaluative substrate is unknown.

Platt & Glimcher (1999) trained rhesus monkeys in a color-cued eye saccade task. The correct left or right saccade was rewarded with a squirt of juice. This study showed that

[11] Orbitofrontal cortex, or else 'OFC', is a region of the brain thought to integrate cognitive and emotional inputs.

projections from the visual cortex converge in area LIP[12] before being relayed to the motor cortex for execution. These researchers thus suspected that area LIP was being used to evaluate rewards. They found that 62.5% of area LIP neuron activation was correlated with expected gain. A few years later, Glimcher and colleagues (2004) argued that the utility function that economists presumed existed to explain behavioral data is a physiological reality in area LIP. However, this does not preclude the existence of other brain regions that are utility functions. Glimcher and colleagues (2004) supported this claim by showing that area LIP firing rates can be used to predict the behavior of monkeys in several reward acquisition tasks. (Zeki et al. 2004: 1741)

There have also been studies that have linked reward with social behavior. For instance, Corcos and Rizopoulos (2011) emphasized the fundamental role of reward and punishment circuits in prosocial behaviors. When individuals choose to help finance a public good or to give to a charitable institution, the reward circuit is activated. (19) Corcos and Pannequin 2011: 17) In another study, Singer et al. (2004) used the Prisoner's Dilemma in order to demonstrate that simply seeing the face of a person who had previously cooperated activates reward circuit areas of the brain. Thus, adopting cooperative behavior and obtaining mutually beneficial behavior will produce an activation of the reward circuit implying a sort of gratification. (Graziano 2013: 38)

Additionally, one of the most important discoveries made by neuroeconomics is the correlation of important processes with the neural structures situated in the most ancient part of the brain, namely "dopaminergic systems", which are involved in motivation and evaluation. The first evidence came from a study conducted by Olds and Milner (1954) who noticed an increase of dopamine in certain brain regions in mice when they were involved in rewarding activities, and thus established a direct causal link between the feeling of pleasure and dopamine. However, this interpretation has now been called into question. (Daw and Tobler 2014: 287, Graziano 2013: 35)

Other neuroscientific studies have demonstrated the link between dopamine and learning through experience. In these studies the dopaminergic response is transferred from an unconditioned stimulus (the reward itself) to a conditioned stimulus (the reward announcer). Schultz and colleagues (1997) reviewed single-neuron firing studies of juice rewards in non-human primates and identified dopaminergic neurons in the ventral tegmental area and substantia nigra as processing rewarding stimuli, activating during novel stimuli, and most importantly, firing proportional to the error of the actual to the expected reward. The dopaminergic neurons, which initially are triggered by the arrival of the reward, therefore, are activated later particularly in light of the conditioned stimuli. As a result, Schultz and her collegues introduced the temporal difference mathematical model to show how dopamine

[12] The lateral intraparietal cortex (area LIP) is found in the intraparietal sulcus of the brain. This area is most likely involved in eye movement, as electrical stimulation evokes saccades (quick movements) of the eyes.

neuron activity can be used to predict an animal's behavior as it learns about rewards. (Graziano 2013: 35, Zeki et al. 2004: 1741-42)

Further studies have shed some light on the neural basis of reward associated decision-making. Some findings indicate that reward value-related information is processed in immediate target regions of the striatum, such as the pallidum, and their target regions, such as the lateral habenula[13]. According to Dow and Tobler (2014: 287) reward-related signals carried by dopamine may influence action selection in the striatum, for instance by affecting plasticity there so as to reinforce rewarded actions and make them more likely to recur. (Daw and Tobler 2014: 287) Moreover, reward is linked with neurons in the internal globus pallidus[14], the substantia nigra[15] pars reticulate and the lateral habenula respond to reward probability. Also, neurons in the lateral habenula code reward probability in an inverse manner to dopaminergic neurons, showing increased suppression of firing rates to stimuli predicting reward with increasing probability. The habenula could feed this probability information to dopamine neurons. Therefore, a variety of subcortical regions process reward probability but decomposition into probability versus magnitude largely remains to be investigated. (Tobler and Weber, 2014: 162)

3.3 Learning

The standard assumption in economics is that individuals learn optimally. A small minority of behavioral and experimental economists has instead argued that learning occurs through simpler strategies such as reinforcement learning, more complicated strategies such as belief learning or fictitious hybrid models such as experience-weighted attraction (EWA) and impulse-matching learning. (Konovalov and Krajbich 2019: 151)

The first learning mechanism was identified, as described in the previous section, in the 1990s by Schultz and colleagues (1997). They demonstrated that the dopaminergic neurons of the striatum and the frontal cortex are able to encode the reward-prediction error. The showed that the reward itself yields higher activity in dopamine neurons, but after the reward is paired with a conditioned visual stimulus, and as this link is learned by the animal, the reward itself no longer elicits a response. When the expected reward is not delivered, the activity of dopamine neurons is depressed, reflecting a negative prediction error. (Konovalov and Krajbich 2019: 152, Zeki et al. 2004: 1741-42)

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[13] The habenula refers to refers exclusively to this separate cell mass in the caudal and dorsal aspect of the dorsal thalamus (the epithalamus). The habenula was traditionally divided into lateral (limbic) and medial (motor) parts. The lateral habenula (LHb) is consisted of neurons that are 'reward-negative' as they are activated by stimuli associated with unpleasant events, the absence of the reward or punishment especially when this is unpredictable. Reward information to the lateral habenula comes from the internal part of the globus pallidus.

[14] The globus pallidus is a subcortical structure of the brain. It consists of two adjacent segments, one external, known in rodents simply as the globus pallidus, and one internal, known in rodents as the entopeduncular nucleus. It is part of the telencephalon and it is involved in the regulation of voluntary movement.

[15] The substantia nigra (SN) is a basal ganglia structure located in the midbrain that plays an important role in reward and movement.

More recently, Zeki and colleagues (2004: 1743) have stated that learning is influenced by both the dopaminergic system and emotional responses. These systems contribute to the update of memories of past experiences using the present experience, thus creating a basis for making informed future decisions. In a recent study, Lee and Seo (2007) showed that, while monkeys work on learning about decisions from rewards, there is evident activity on the frontal cortex and also on the posterior parietal cortex, which is classically thought to be involved in the so-called dorsal visual processing stream. (Trommershäuser 2011: 4) These findings suggest that the brain is able to evaluate. Hence a necessary choosing stage, which takes the evaluations of various options as input, enables the physical action of the decision-maker to be guided. (Corcos and Pannequin 2011: 26)

These findings provide evidence of reinforcement learning (RL) in the process of decision-making. RL is a field that extends decision-theoretic accounts to situations involving learning. It is a learning algorithm where agents use feedback from previous experience to update the representation of a stimulus or environment. This theoretical framework, which involves several statistic principles, has been used to explain the role of learning both in traditional choice tasks, and in sensimotor adaptation. Reinforcement learning also plays an important role in the study of the neural processes underlying these functions, as it is involved both in motivated decisions and in movement. (Camerer 2003: 1674, Frydman, and Camerer 2016: 662, Trommershäuser 2011: 4)

In a careful study, Barraclough et al. (2004) investigated reinforcement learning and reward encoding in two rhesus monkeys trained to play a variant of matching pennies' against a computer using three different strategies. A reinforcement earning statistical model fitted the monkeys' choices quite well showing that the history of play by the computer affected the monkeys' current choices. These researchers also recorded the firing of 132 separate neurons in the DLPFC[16] during monkey choices, either by the previous reward, or by the previous choice. Thus, the DLPFC may be part of the neurophysiology of reward acquisition, especially when this involves memory-dependent strategic decisions. Reinforcement learning also involves neural activation in the amygdala, the OFC , the vmPFC and the striatum. In humans, the DLPFC, which activates during working memory tasks, may be another physiological utility function. That is, the current value of a reward may be affected by the memories of obtaining similar rewards. If this result is confirmed by other studies (especially in humans), it suggests an important modification to the classical economic model of utility. (Konovalov and Krajbich 2019: 151, Zeki et al. 2004: 1743)

Recent studies corroborate the idea that the brain has two distinct learning systems, one being habitual (or reinforcement-based, or model-free) and the other one being goal-directed (or model-based). The second one is associated with prospective thinking, where subjects appear to consider the value of future states at the time of the initial choice. It is typically observed that human brains employ a mixture of both algorithms, though the model-

[16] The dorsolateral prefrontal cortex (DLPFC) is an area in the prefrontal cortex of the brain of humans and non-human primates. It is one of the most recently derived parts of the human brain. It undergoes a prolonged period of maturation which lasts until adulthood. The DLPFC is not an anatomical structure, but rather a functional one. An important function of the DLPFC is the executive functions, such as working memory, cognitive flexibility, planning, inhibition, and abstract reasoning.

free and model-based strategy are weighted differently across people. The two systems might be of great importance for economic applications because model-free and model-based learning have been linked to strategic behavior and also to problems of dietary choices, addiction and self-control. (Konovalov and Krajbich 2019: 154-155)

3.4 Social Learning

In recent years it has been suggested that is similar to basic reinforcement learning. During the interaction with peers, ventral striatum and OFC seem to track predictions about whether a social agent will give positive social feedback and ACC correlates with modulation of expected value associated with the agents. It has also been proposed that social information may be acquired using the same associative processes assumed to underlie reward-based learning, but in separate regions of the ACC.

However, social decisions often contradict economic models that attempt to predict social behavior, as social behavior is more complex than previously thought. Tversky and Kahneman (1974) were the first to point out biases and heuristics that may be used in a social decision-making context. For instance, when playing the trust game, participants may use initial impressions formed about the person (based on a representative heuristic about what trustworthy people look like) as an anchor that affects whether or not they invest with the partner on subsequent trials, and also how much they invest.

People also possess several other biases that affect how they interpret information. For example, they have the tendency to look for information that is consistent with a preexisting belief. This confirmatory bias is evident in studies which demonstrate that people interpret ambiguous information as consistent with or as a confirmation of a stereotype about a person. At the same time, people often exhibit illusionary correlations, which means they see a relationship between two things when one does not exist, and are more likely to attribute a person’s behavior to the person rather than to some situational factor.

Studies have shown that social learning is a combination of all previous processes and biases. To study how the combination of impressions and behavior affect social decision-making, Chang et al. (2010) used mathematical models based on reinforcement learning to test specific hypotheses about how these two types of information guide social decisions in a repeated trust game. From all models, the Dynamic Belief model fit the data the best. The Dynamic Belief model assumes that initial impressions are continuously updated based on the participant’s experiences in the trust game and these beliefs then influence learning. In this model, equal emphasis is placed on the initial judgment and the participant’s experience. That is, initial trustworthiness is simultaneously influencing learning and being updated by experience. As a result, this study suggests that both social cognition processes (initial impressions) and decision-making processes (feedback processing) affect social learning in the trust game. (Lee and Harris: 9-10)

3.5 Social decision making

According to Ross (2006: 247, 257):

> "Human behavioral patterns are mainly social and collective phenomena […] social dynamics are logically and ontogenetically prior to individual selves, because selves are sculpted into being by social processes".

However, the way people treat their fellow humans doesn't present a common pattern, as in the case of decision-making under risk. Some economists believe that pure selfishness prevails. However, this notion is contradicted by the very behavior of individuals and also by several neuroeconomic experiments that have been conducted. These experiments contradict some of the basic assumption of neoclassic economic theory, such as the notion that rational subjects are egocentric and always chose actions that promote the maximizing of their individual satisfaction, without having any interest in satisfying or not satisfying other people. They also emphasize the role of social preferences in the process of decision-making. Social preferences are a characteristic of an individual's behavior or motives, indicating that the individual cares positively or negatively about others' material payoffs or well-being. Thus, individuals with social preferences display other-regarding motives, such as taking into account the welfare of other individuals. (Fehr and Krajbich 2014: 193)

As a result, many competing models of social preference have emerged, whereby individual satisfaction links an individual's gains with those of others, based on arguments of reciprocity or aversion to inequity. (Corcos and Pannequin 2011: 16) All of these models assume that subjects' utility functions depend, not only on their own material payoff, but also on nonmonetary payoff elements such as concerns for fairness, reciprocity, equality, or efficiency. For example, in theories of reciprocal fairness kind intentions are positively valued by other players, whereas hostile intentions are negatively valued. Thus, if player A reduces B's payoff to his own benefit, a reciprocal player B will punish A, whereas if the income was redistributed from B to A due to bad luck, a reciprocal player B will not punish. On the contrary, if a player is characterized by inequity aversion[17], player B will be induced by bad luck to act in order to redistribute income. Similarly, some theories postulate an individual's desire to maintain a positive social image, or to increase the economic welfare of the group to which they belong. (Fehr and Krajbich 2014: 196)

[17] Inequity aversion is a dislike of unequal outcomes.

Thus, in contexts of social interaction, social dilemma tasks such as the Ultimatum Game[18], the Dictator Game[19], the Trust Game and the Public Goods Game have shown that choices cannot be attributed to self-interest alone. (Corcos and Pannequin 2011:16, Fehr and Krajbich 2014: 196) These games were developed within the framework of game theory, to investigate the neural underpinnings of social exchange and mutual cooperation. They involve real monetary stakes and are played between anonymous interaction partners. (Singer and Tusche 2014: 514)

Experiments using the Ultimatum Game (UG) have convincingly demonstrated that decision-makers are in general not self-interested, being disposed to punish adversaries who make offers perceived as being unfair, despite this being costly for them. According to the model of *homo economicus*, a rational economic agent should in theory accept all non-zero offers in the Ultimatum Game, since any amount of reward is better than nothing. However, in reality, human beings have a strong tendency to measure their rewards against the rewards of their peers, which is a form of irrational behavior. (Kirk et al. 2011: 41) As Sacco and Zarri (2003) emphasize, the participant of the UG game is self-interested from a motivational point of view, but in fearing that a low offer might be rejected by the adversary, the player takes precautions and makes offers which could be perceived as fair and that could reasonably be accepted by the other player. (Graziano 2013: 41) In most populations the proposer offers 40-50 percent and about half the responders reject offers less than 20 percent. (Camerer et al. 2005: 47) When we compare the offers the proposers typically make in ultimatum games to those made in dictator games, we find that they typically offer less in dictator games. (Singer and Tusche 2014: 515-516)

Another social dilemma task is the Prisoner Dilemma[20]. The simultaneously played Prisoners' Dilemma (PD) is a special case of a public goods game, and it is well known that many people are willing to cooperate in this game if they believe that their opponent will cooperate as well. However, if they believe that their opponent will defect, they will do the same. (Fehr and Krajbich 2014: 196) Social cooperation in the Prisoner's dilemma engages a set of structures, including the orbitofrontal and anterior cingulate cortices and the ventral striatum. (Adolphs 2003: 173)

[18] The Ultimatum Game (UG) is an economics experiment that provides some interesting insight into the human psyche. In this game two parties interact anonymously and only once, so reciprocation is not an issue. The first player, Mover One (M1) is given a certain amount of money and can then decide how much he/she wants to share with Mover Two (M2). M2 looks at the offer and can then decide whether he/she wants to accept or reject it. If the offer is rejected, no one receives any money. Such a move can be conceived of as a way to punish M1. However, if M2 were purely interested in money, he/ she would accept any possible offer from M1, irrespective of whether this offer is deemed fair or unfair. If the offer is accepted, M1 gets her demand and the M2 gets the rest.

[19] The Dictator Game is another game that has been used in neuroscientific studies. It is similar with the Ultimatum Game with the difference that in this case M2 is neither allowed to reject nor accept the offers made by M1, but just passively receives whatever is offered.

[20] The Prisoner's Dilemma is a paradox in decision analysis in which two individuals acting in their own self-interests do not produce the optimal outcome. The typical prisoner's dilemma is set up in such a way that both parties choose to protect themselves at the expense of the other participant. As a result, both participants find themselves in a worse state than if they had cooperated with each other in the decision-making process. The prisoner's dilemma is one of the most well-known concepts in modern game theory.

These experiments have also provided important evidence for neuronal processes involved in social decision-making. For instance, during the Ultimatum Game both parties showed a marked difference in the activity of the anterior insula. According to Sanfey and colleagues (2003), in previous studies of the UG, anterior insula activity was higher for unfair offers, and the strength of its activity predicted the likelihood of an offer being rejected. The anterior insula has previously been linked to the emotion of disgust, and plays a key role in social norm violations, rejection, betrayal, and mistrust. (Kirk et al. 2011: 45) Moreover, according to Graziano (2013: 37) the prefrontal cortex, along with other structures such as the anterior cingulated cortex and the insula, seems to be involved in the regulation of social interactions and behavioral conduct so that they are handled in a timely manner.

3.6 Emotions

It has been suggested that emotions can also affect our behavior, especially in the framework of social interactions. (Corcos and Pannequin 2011: 16, Trzaskowski 2011: 389) According to Lempert and Phelps (2014: 220), the term emotion is generally used to describe a set of discrete reactions to an internal or external event, which can yield physiological responses linked to the action of the autonomic nervous system, facial or bodily expressions, and changes in subjective feelings. Although all of these reactions may be synchronized, they may not all be present and they can vary independently in their intensity. As Sanfey and collegues (22) 2006:112) stated:

> "Emotions are rapid, highly automatic responses to specific stimuli or events, well adapted to some circumstances but not to others".

Emotions are generally separated into two categories, 'basic emotions' and 'social or moral emotions'. The first include emotions such as happiness, fear, anger, disgust, and sadness, whereas the later includes guilt, shame, embarrassment, jealousy, pride and other states that depend on a social context. Social emotions arise later in development and evolution and require an extended representation of oneself as situated within a society. They regulate social behaviors, often in the long-term interests of a social group rather than the short-term interests of the individual person, and guide altruistic helping and punishment. (Adolphs 2003: 166, 176)

According to Greene and colleagues (2001), emotions play a causal role in personal moral dilemmas. This study showed that found that participants took significantly longer to make utilitarian judgments that went against the emotional response in the personal moral dilemmas than to make emotionally congruent judgments. The results suggest that the personal moral dilemmas elicit a strong emotional response that must be cognitively overcome in order to respond in a manner inconsistent with the emotion. (Loewenstein et al. 2008: 662) Another study showed that, brain regions consistently associated with emotional processing, such as medial frontal and posterior paracingulate cortex, were more active when participants considered personal moral dilemmas than when participants considered impersonal moral or nonmoral dilemmas. (Fehr and Krajbich 2014: 209-10)

At the same time, neuroeconomics shows that many decisions prove correlated to the neural activity of emotional circuits. Erk and colleagues (2002) showed that consumption of products associated with wealth or social status produces pleasure that can be identified in the activation of the reward circuit. Similarly, Deppe and colleagues (2005) found that the presence of a brand appreciated by an individual activates his brain's emotional area, thus providing a correlation between emotions and brand preference. (Corcos and Pannequin 2011: 14)

Another study, by Koenigs and colleagues (2007) also found that emotions play a causal role in personal moral judgments. Participants either had lesions to VMPFC[21], lesions to brain regions not directly associated with emotional processing, or no brain lesions, or were confronted with a series of moral and nonmoral dilemmas. Given that patients with VMPFC lesions typically show diminished emotional responsivity in general and severely reduced social emotions (e.g., shame) in particular, these participants were predicted to find utilitarian judgments more palatable in the personal moral dilemmas as compared with normal and lesion control participants. Indeed, Koenigs et al. (2007) found that the frequency of utilitarian judgments did not differ by participant type in the nonmoral and impersonal moral conditions, but that participants with VMPFC lesions were most likely to make utilitarian judgments in the personal moral condition. (Loewenstein et al. 2008: 662-63)

It is also important to mention the effect of negative emotions in decision-making. For example, many important decisions are made under stress. Various research have shown that people tend to be risk-seeking in the loss domain and risk-averse in the gain domain. In an experiment by Porcelli and Delgado (2009) provided evidence that exposure to stress exaggerated this tendency; individuals who had undergone stress became more conservative in the gain domain, and more risky in the loss domain. Furthermore, Kassam and colleagues (2009) found that under stress, participants were more likely to use irrelevant information to answer difficult questions, and the degree of this bias was correlated with their physiological stress response. (Lempert and Phelps 2014: 221)

Other emotions, such as envy and schadenfreude are also important. Envy can be described as a negative emotional state in the face of another's fortune, while schadenfreude refers to a positive emotional state in the face of someone else's misfortune. According to Singer and Tusche (2014: 526), several findings indicate that the opposing motivational systems of empathy on one side and envy, schadenfreude or revenge on the other side can be predictive of engagement in prosocial or egoistic behavior.

Neuroeconomics have shown that most structures that are important in processing emotions have also turned out to be important for social behavior. The first set of structures includes specific regions in higher-order sensory cortices, which are involved in the perceptual representation of stimuli and their constituent features. The second involves the amygdala,

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[21] The Ventromedial Prefrontal Cortex (VMPFC) is a part of the prefrontal cortex in the mammalian brain. The VMPFC is located in the frontal lobe at the bottom of the cerebral hemispheres and is implicated in the processing of risk and fear, as it is critical in the regulation of amygdala activity in humans. It also plays a role in the inhibition of emotional responses, and in the process of decision making and self-control. It is also involved in the cognitive evaluation of morality.

the ventral striatum and orbitofrontal cortex, which mediate an association of this perceptual representation with emotional response, cognitive processing and behavioral motivation. Especially, the amygdala is well known as a region responsible for emotional processing and is thought to be critical to social behavior. Indeed, patients with lesions to the amygdala are impaired in recognizing emotional expressions, show diminished loss aversion, less sensitivity to encroachments on their personal space, and respond less negatively to untrustworthy behavior. The third set of structures is consisted by additional cortical regions such as the left prefrontal, right parietal, and anterior and posterior cingulate cortices, which are involved in the construction of an internal model of the social environment, involving representation of other people, their social relationships with oneself, and the value of one's actions in the context of a social group. There is a general consensus that high-level, deliberative processes, such as problem-solving and planning, consistently engage anterior and dorsolateral regions of prefrontal cortex as well as areas of posterior parietal cortex. To some extent, these three sets of processes build on one another, although their interactions are complex. (Adolphs 2003: 166, Breiter et al. 2001: 632, Fehr and Krajbich 2014: 209-10, Lempert and Phelps 2014: 219, Sanfey et al. 2006: 112)

3.7 Trust, Cooperation and Empathy

Trust and cooperation are also two key components of decision-making. In neuroeconomics, variants the Trust Game[22] has been widely examined in order to extract important information about these elements. Although simple, this game is useful in identifying and studying many facets of human preferences and behavior from theory of mind, to altruism, to betrayal aversion, and many other decision-making factors. Although *homo economicus* does not trust and is never trustworthy, he does not connect to, or rely on others, these studies have shown that trust and cooperation among humans, especially among strangers, is higher than predicted by most economics and biological models. (Aimone and Houser 2016: 657-58, Park and Zak 2007: 48, 51)

These studies show that we allow ourselves to trust others because the hormone oxytocin reduces our fear of interacting with others and motivates us to reciprocate when trusted. We also trust using cognitive mechanisms associated with determining others' likely choices and, we reciprocate because our brains make cooperation rewarding. (Park and Zak 2007: 48)

[22] The Trust Game, designed by Berg et al. (1995) and otherwise called "the investment game," is the experiment of choice to measure trust in economic decisions. The experiment is designed to demonstrate that trust is as basic to economic transactions as self-interest.). In this game, a first mover—the investor—can send a portion of his or her monetary endowment to a second mover, the trustee. On being sent, the money is multiplied by, typically, a factor of three, thus reflecting gains from
trade. The trustee then has the option to send a portion of this now larger pot of money back to the investor. Any amount sent is considered to reflect trust on the part of the investor because there are no guarantees that the trustee will send back anything. Any amount returned by the trustee is considered reciprocation.

An important study, involving the Trust Game, was conducted by McCabe et al. (2001), who reasoned that cooperative economic exchange requires theory-of-mind[23] (ToM). Their hypothesis was that the medial prefrontal cortex, which had previously been implicated in ToM processing, would also mediate cooperative economic exchange. In order to test this hypothesis, they used fMRI to measure brain activity when subjects played games involving trust, cooperation and punishment. They asked subjects in a scanner to play variants of a Trust Game multiple times with either human counterparts outside the scanner or with a computer counterpart, which would play a human-like strategy. All trust games were binary, in the sense that both the investor and trustee chose from one of two alternatives, either cooperate or defect. The computer played a known stochastic strategy, and scanner participants were informed prior to each game whether their counterpart was a human or a computer. (Camerer et al. 2004: 570, Camerer et al. 2005: 47, Houser and McCabe 2014: 30)

They found that subjects were more likely to cooperate with real humans than with computers and that cooperators have a significantly different brain activation in the two conditions. More specifically, seven of the twelve subjects were consistently cooperative. Among this group medial prefrontal regions were found to be more active when subjects were playing a human than when they were playing a computer. On the other hand, within the group of five non-cooperators there were no significant differences in prefrontal activations between the human and computer conditions. Thus, players who cooperated more often with others showed increased activation in Brodmann area 10 (thought to be one part of the mind-reading circuitry) and in the thalamus (part of the emotional "limbic" system). Players who cooperated less often showed no systematic activation. (Camerer et al. 2004: 570, Camerer et al. 2005: 47, Houser and McCabe 2014: 30, Glimcher and Rustichini 2004: 452)

Another important finding of neuroeconomics studies is the role of evolutionary old brain structures in supporting trusting behaviors. According to Park and Zak (2007: 52), many of the brain regions that produce trust and reciprocity are associated with emotional responses. Thus, we seem to have an intuitive, emotional approach to trust, rather than a cognitive deduction based on costs and benefits. Genes, life-histories and changing environments might affect brain functioning and impact the decision on whether to trust another. (Park and Zak 2007: 52-54) argue that the important role of the unconscious and emotional factors in choice also has important implication for policy design and institutional structure.

Other researches have also confirmed that social interaction with others is particularly gratifying. For example, Singer and colleagues (2004) used the Prisoner's Dilemma and demonstrated that simply seeing the face of a person who had previously cooperated activates reward circuit areas of the brain. The adoption of cooperative and mutually beneficial behavior produce an activation of the reward circuit implying a sort of gratification. (Graziano 2013: 38)

[23] Theory of mind is the ability to attribute mental states — beliefs, intents, desires, emotions, knowledge, etc. — to oneself, and to others, and to understand that others have beliefs, desires, intentions, and perspectives that are different from one's own. Theory of mind is crucial for everyday human social interactions and is used when analyzing, judging, and inferring others' behaviors.

Another important aspect of decision-making is empathy, the ability to understand and share the feelings of another. Empathy is likely to render people less selfish because it enables them to share others' emotions and feelings, thereby motivating other regarding behavior. Accordingly, empathy has very often been related to morality, altruism, justice, prosocial behavior, and cooperation. Some behavioral and imaging evidence suggests that people help others more when they report having empathized or show enhanced empathy-related brain activation with them. (Singer and Tusche 2014: 515-517) Moreover, empathy (and oxytocin) contributes to building trust and thus it could have clear implication 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. (Park and Zak 2007: 55)

According to Singer and colleagues (2004) empathic response is rather automatic and does not require active engagement of some explicit judgments about others' feelings. (Singer and Fehr 2005: 342) Recent meta-analytic findings about empathic responses in various domains including emotional and physical pain, taste, and disgust and even for higher-order emotions such as embarrassment and social exclusion, have shown that brain regions such as the anterior cingulate cortex (ACC) and the anterior insula (AI) play a central role in empathy for others. (Singer and Tusche 2014: 520-21) For instance, in a recent fMRI study, Hein and colleagues (2010) investigated whether social group membership impacts the empathic responses to the suffering of another person and the willingness to engage in costly helping. Using an empathy-for-pain paradigm, soccer fans expressed increased empathic concern for the suffering of members of their favorite soccer team (ingroup) compared to members of the rivalry team (outgroup). In line with previous findings, the self-reported degree of empathic concern was reflected in neural responses in the AI. (Singer and Tusche 2014: 523)

Chapter 4. Critical Review of Neuroeconomics

4.1 Arguments against Neuroeconomics

The main vision of neuroeconomics is to use the additional information obtained from brain studies, combined with the choice made by the decision maker, in order to better understand the deliberation process and to use the results to improve economic models. However, according to some critics of neuroecomics, it is far from being clear if and how this can be accomplished. (Rubinstein 2008: 492)

According to some theorists economic hypotheses cannot be falsified using neuroscience data. They judge the scientific relevance of neuroeconomics in terms of its ability to confirm and reject existing economic models and to provide alternatives. This argument is called *Behavioral Sufficiency.* Economic models make no assumptions about the mechanisms underlying behavior and draw no conclusions about the physiology of the brain, and thus no data about those mechanisms could confirm or refute any economic model. To falsify an economic model, researchers must manipulate some environmental factor and observe a change in behavior contrary to the model's predictions. As a result, behavioral data are both necessary and sufficient to evaluate the validity of economic models, leaving only brain function or clinical disorders for neuroeconomics to address. (Aydinonat 2010: 159-60, Clithero et al. 2008: 2349)

However, Behavioral Sufficiency rests on the premise that the data necessary to falsify or support a model can, in practice, be identified and collected. Many important decision phenomena require a wide range of tests for their experimentation. The accumulation of the necessary data might be time-consuming and expensive, especially when testing interacting factors, but it is possible. However, no researcher can obtain all possible data about all possible behaviors. These practical limitations leave an opening for neuroscience data to influence economic modeling by directing the course of research. Thus, neuroeconomic researchers could test effects of a whole range of affective states (such as anger or sleep deprivation) and, using comprehensive data about how preferences change across these states, they could validate, reject, or refine relevant economic models. Thus, neuroeconomics should be judged by its ability to improve economic explanations and models, and more generally by its ability and potential to improve our understanding of economic phenomena. (Aydinonat 2010: 160, Clithero et al. 2008: 2349)

A second criticism focuses on the methods of neuroeconomics, which frequently place human or non-human subjects in a mock economic setting to elicit a desired behavior—such as differential framing of gains and losses, or rejection of unfair offers (Clithero et al. 2008: 2349) In effect, these studies create a simplified "toy model" of a real-world phenomenon in order to test hypotheses about an underlying mechanism. Neuroeconomic experiments typically follow basic research principles, such as the offer of full and accurate information to the participants, the condition that decisions should have meaningful (usually monetary) consequences, and the prohibition of deception. Thus, the validity of a toy model rests on the assumption that the principles of interest are maintained from the laboratory setting to the natural environment. However, when the physical principles change, an extrapolation from toy models may have disastrous consequences. In the same way, neuroeconomic principles that shape behavior in the laboratory do not necessarily influence real-world phenomena. This argument is referred to as the *Emergent Phenomenon* argument, which is the denial that an understanding of mechanism has relevance for understanding phenomena at the aggregate societal level.

The *Emergent Phenomenon* argument, however, rests on the assumption that emergence not only exists but subsumes any influences from lower levels. However, in many occasions lower levels provide important and useful information. For example, although some economic phenomena have some emergent properties that restrict the explanatory power of hierarchical, mechanistic models, that characteristic does not render those models logically invalid. Social science models are now increasingly likely to incorporate some mechanistic explanations that account for effects across levels. For instance, economic experiments aimed at implementing general equilibrium theory in the laboratory use individual portfolio choices to explain financial market behavior. To the extent that researchers can more accurately specify the mechanisms underlying the behavior of an individual, some phenomena of interest to economists will be better modeled. A core goal of neuroeconomics will be identifying those economic phenomena to which neuroscience can be most profitably applied. (Clithero et al. 2008: 2349-50)

Additionaly, some theorists doubt that theoretical constructs of neuroscience, economics and psychology are commensurable. For instance, they point out a slippery logical practice that has pervaded the field of neuroeconomics consists in inferring to the engagement of a particular cognitive process from the activation of a particular brain region on the sheer basis of similar past inferences. This logical move is called a reverse inference. However, epistemological safety may be restored either by complying with the constraints that license functional inferences from observed neural patterns to cognitive processes and states, or by relying on an altogether different way of interpreting neurobiological mechanisms which underlie economic behavior. A possible solution would be that neuroeconomics use experimental paradigms in order to generate their own measure of neural selectivity. For instance, repetition suppression paradigms have been used, in the context of the investigation of low level brain processes such as perception, in order to determine the selectivity of a region. Repetition suppression is a reduction of neural response that can be observed when stimuli are presented several times. Finally it could be stated that solving the reverse inference issue consists in developing a clear preview of the structural organization of the brain in response to tasks that are of interest for the behavioral economist (Bourgeois-Gironde 2010: 230-32, 242, 246)

Another argument against neuroeconomics is the so called 'mindless economics' case. This argument rests on the hope that all anomalies produced by behavioral economics and neuroeconomics can be explained (if not predicted) by the enriched language of economics. However, neuroeconomics has proven very useful in the case of localizing in the brain areas linked to imperfections and constraints that economics try to explain. Neuroeconomics provides brain evidence which is useful for understanding several imperfections, biases, and constraints and suggests the best models for them. (Camerer 2007: C39, Rubinstein 2008: 492-93)

4.2 Is Neuroeconomics Useful?

Neuroeconomics strives to link observed behavior, mathematical constructs, and mechanistic details of choice. Camerer, Loewenstein, and Prelec (2004, 2005) have portrayed economic models as unrealistic models that fail to address questions concerning important aspects of economic phenomena. They think that neuroeconomics shows the deficiencies of existing economic models and helps us refute or accept models and explanations in economics. (Aydinonat 2010: 159) It is widely accepted that the model of *homo economicus* does not represent reality. Human beings don't make choices only according to the maximization of their personal interest. They are influenced by other factors, such as emotion, several cognitive biases, previous knowledge and general changes in their environment.

Neuroeconomics, although criticized by some theorists, has proven very useful for the understanding of the human psyche and the creation of economic models that better represent the process of decision-making. According to Clithero and colleagues (2008: 2350), neuroscientific experiments can guide the generation and direction of future behavioral studies with a multi-stage "behavior-to-brain-to behavior" approach via *Mechanistic Convergence*. Thus, by identifying interesting choice behavior and creating models for the associated cognitive processes, neuroeconomics research can generate better paradigms for human neuroimaging studies and target behavior to replicate in animal and clinical studies (*behavior*). Neuroeconomics can ground conclusions about brain function in behavioral effects such as choice parameters or individual decisions, and can thus unify cognitive and neural theories of behavior. Well-designed neuroscience experiments can speed the course of behavioral research, effectively using mechanistic knowledge to target observable behaviors for subsequent experimentation. (66) Clithero et al. 2008: 2350-51)

As Park and Zak (2007) have portrayed, neuroeconomics' findings are relevant for economics and they may help in improving economics. For instance, apart from producing new hypotheses, neurobiological knowledge can also introduce constraints. Models of neural function have guided theories of executive control and decision making. Likewise, neuroscience can inspire models of behavior that conform to our current scientific knowledge, that is, behavioral models that have *Biological Plausibility.* The advantages of mechanistic knowledge are well documented in the psychological, philosophical, and economic literatures. For instance, a combination of rodent, nonhuman primate, and human studies have led to theorizing about the role of dopamine in reward processing and prediction error. Thus, neuroeconomics use ideas that have been presented in economics, such as game theory and expected utility theory and try to explain the responses of individual neurons to incoming information. (Clithero et al. 2008: 2351)

Neuroeconomics is providing important insights into an important issue of economics, rationality. The traditional view in economics suggests that decisions are made after careful deliberation of costs and benefits determined through one's preferences and the constraints faces. Rationality according to economics is thus viewed as consistency in choices. However, neuroeconomic research is showing that most brain processes are unconscious. (Park and Zak 2007: 51)

Another area in which neuroeconomics are providing insights is choices that involve others. Trust among humans has proven to be higher than previously predicted by most economics and biological models. More generally, operative behaviors, especially with strangers, are higher than predicted. (Park and Zak 2007: 51) Moreover, neuroeconomic approaches to understanding social decision making have begun to shed light on the precise mechanisms through which neuromodulators, such as serotonin, oxytocin and dopamine, can shape social interactions. (Crockett and Fehr 2014: 275)

As for explaining particular cases in economics, correct theoretical explanations in economics could also benefit from neuroeconomics' theoretical insights concerning particular details (e.g. concerning preference formation, decision making, etc.) about the particular individuals and markets (Aydinonat 2010: 167-68) Thus, neuroeconomics can make important contributions to research on decision-making – firstly, the incorporation into neuroscience and psychology of the formal, rigorous economic modeling approach, and secondly, the awareness within the economic community of the evidence for multiple systems involved in decision-making. (Sanfey et al. 2006: 114)

In conclusion, we can say it is evident that neuroeconomics is a very useful field. It gives answers to questions which other fields cannot solve, providing important insights to the decision-process and the biases that leads to sometimes irrational behavior. There might have been some criticism towards neuroeconomics, but we cannot forget that it is an upcoming field that can still develop. New technologies can be incorporated in the future and the various research methods and data can still be perfected. For example, a current challenge of neuroeconomics is to ensure that researchers are communicating productively because often, terms such as 'choice', 'judgment' and 'decision' are used in different ways by different fields. Consequently, it would be useful to arrive at a common language, and perhaps a common set of 'decision tasks', to ensure that the collaboration across these diverse fields continues in a productive fashion. (Sanfey et al. 2006: 114) Neuroeconomics also seems promising because in the future it might shed more light in the way changes within our brains yield different behavioral outcomes. There much obvious future research. One path is to search for evidence of distinctions that are well-established in behavioral economics (such as gain-loss differences, framing effects, emotional foundations of inequality-aversion or social image, and so forth). (Camerer 2007: C39)

Chapter 5. Conclusion

In the economic field, when we talk about markets or decisions, we refer to expectations, forecasts, probabilities and estimates. People are constantly affected by the changes in their surrounding environment and create either positive or negative expectations. The high importance of expectations derives from their capacity to influence human psychology. When the expectations are positive, the value of the purchase a consumer makes tend to increase, leading to an expensive purchase that he/she probably wouldn't have made under different circumstances. In the contrary, when the expectations are negative, consumers tend to be more skeptical about their purchases, their investments and their overall economic decisions.

It is thus evident that our need to study the economic behavior of human subjects is inextricably linked with the need to study their psychological profile and processes. Every human being is different and as a result, the psychological analysis we chose to make must be more general. It must involve all subjects, assuming that they will react in the same way, either choosing A or B. In the beginning of economic science, the model of *homo economicus* was dominant. According to this model, the rational subject has the ability to make decisions that would maximize his profitability or his prosperity under any circumstances of stress, anxiety or emotional burden. This assumption has since been abandoned, as scientists from different fields have accumulated various data and have conducted several studies which showed that humans do not always behave rationally.

Economics parted their ways with psychology in the beginning of the 20th century because economists became skeptical about whether psychological processes could be measured without taking into account human behavior. Neurology was the first field to make this possible. It presented a new way to open the "black box", that is, the human brain, which is the main component of economic systems.

Most economists are curious about neurology but remain skeptical about whether it is a needed factor for economic science. However, many studies have made it clear that neurology will affect economics. Brain neuroimaging will change the beliefs of psychologists who focus on the cognitive restrictions, leading to a chain reaction that will inform existing economic theories in order to conform to new psychological findings. At the same time there are several neurologists and neuroscientists interested in economics. As a result a new interdisciplinary field will rise, the field of neuroeconomics. Economics could continue their research without paying attention to neuroscience. However, it is a dangerous strategy to ignore an important stream of new evidence. It is difficult to believe that an increasing familiarity with brain functions will not lead us to better economic theories.

Various neuroscientific methods have allowed neuroeconomists to make a substantial progress in the decoding of the human psyche, social and economic behavior. It helps us answer some of the most important economic answers, such as "Why do we make irrational decisions?" and "How can we achieve happiness?" Newer neuroeconomic approaches are directly examining how our brain interventions can influence decisions. By measuring brain activity during decision-making, neuroeconomics provide information about processes in the human brain, giving us the opportunity to improve the existing behavioral models or even create new ones.

Thus, how can neuroeconomics inform economics? First, in financial applications, neuroscientific data have a comparative advantage when other sources of data are unreliable, as is often the case in various studies. Given that neuroeconomists "ask the brain, not the person", the data they collect may produce more reliable indicators of some of the variables that are important in economics (e.g., consumer confidence, and maybe even prosperity).

Secondly, neuroscientific research will be able to correlate different hypothesis about various brain functions (area, and activation) with intermediate variables that have not yet been studied (such as utility, beliefs, planning), and the observed behavior. A category of fruitful subjects involves some theories which assume that choice A and choice B are made by a common mechanism, although it may be suggested otherwise.

Thirdly, neuroeconomics can provide evidence that some economic choices which might seem different actually involve the same neural mechanisms. For example, studies have shown that the insula cortex is active when people receive low offers, when they choose between ambiguous gambles, and when they see the faces of people that have previously been cooperative with them.

Fourthly, neuroeconomics can provide more accuracy to the parameters of economic models. The study of the brain and its functions can lead to more details that might be used in human resources and labor market theories. When we study the various neural mechanisms, we increase our knowledge about human behavior. For instance, if the hormone oxytocin is released when we trust, and while we trust a reciprocal feeling is created, then an exogenous rise of the levels of oxytocin might contribute to the increase of trusting behavior. The key point is that understanding the effects of biological and emotional processes, such as the release and distribution of hormones, will lead to new forms of predictions about how variations in these processes affect economic behavior.

The main question is whether it will be possible to create formal models that will explain how the different functions of the brain interact. The answer is “yes”, as the standards already exist. A basic step towards that direction is to understand that our behavior is the result of the interaction between neural mechanisms, which is influenced by our cognition and our emotion. This approach may seem difficult, but we should not forget that economic theories are based on complex approaches. For example, think about concepts such as supply and demand, or about economic interactions between employer and employee. The potential of neuroeconomics to study these complex systems is a result of many years of practical studies, and of theoretical models that were disproved by reality. Thus, the creation of neuroeconomic models which will explain our brain processes might not be more difficult than the effort made by economists to achieve market equilibrium.

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