

# Commentary

## NeuroEconomics: an introductory review

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### 1. OVERVIEW

A new intriguing field of research called *Social Neuroscience* has quickly emerged in the past ten years. Social Neuroscience aims at investigating how the brain and the body affect social behaviours by combining a biological and a social approach, with the goal of informing and refining theories of social processes and behaviours (Harmon-Jones & Winkielman, 2007). In just a few years, social neuroscience has reached many results concerning the biological mechanisms underlying social processes such as *emotion* and *action understanding*, *interpersonal interactions*, as well as the development of *mind reading* and *linguistic abilities*, thus supporting the idea that a new multidisciplinary interaction between social and biological sciences should be further encouraged.

Within the general field of social neuroscience researchers have studied the neurobiological basis of *human decision making*, as well as *risks* and *rewards categorisation*. Such studies have given raise to a new sub-field of scientific research, called *neuroeconomics*. Neuroeconomics investigates the neural mechanisms underlying decision tasks characterized by profitable or unfavourable outcomes. It combines the classical knowledge concerning human economic behaviours and the explanatory power of neuroscience (Schultz, 2008). As for many other new areas of research, the development of neuroeconomics is characterized by contrasting opinions, so that enthusiastic introductions (Glimcher et al., 2008) are coupled with sceptical analysis (Bernheim, 2008; Harrison, 2008) or radical oppositions (Gul, et al., 2008). Despite this fact, a positive stance is actually prevalent in the literature.

Neuroeconomics seeks an explanatory analysis of social and economic behaviours in neural circuitry, using experimental techniques such as fMRI (functional magnetic resonance imaging) TMS (transcranial magnetic stimulation) pharmacological interventions and other methods. The astonishing methodological progress characterizing recent neurobiology makes it reasonable to expect the development of new ambitious programs, changing the boundaries between cognitive neuroscience and traditional social studies. Indeed, the emergence of neuroeconomics is positively correlated with the increasing number of publications linking neurobiological findings with old economic questions (fig. 1) and with the increasing use of the term “neuroeconomics” across many established disciplines such as biology, economics and philosophy (fig. 2). Since 2002 at least four major journals from neuroscience, economics and philosophy, have dedicated a special issue to neuroeconomics (Neuron, 2002; Games and Economic Behavior, 2005; Philosophical Transactions of the Royal Society, 2008; Economics and Philosophy, 2008). Articles about neuroeconomics have appeared in several newspapers

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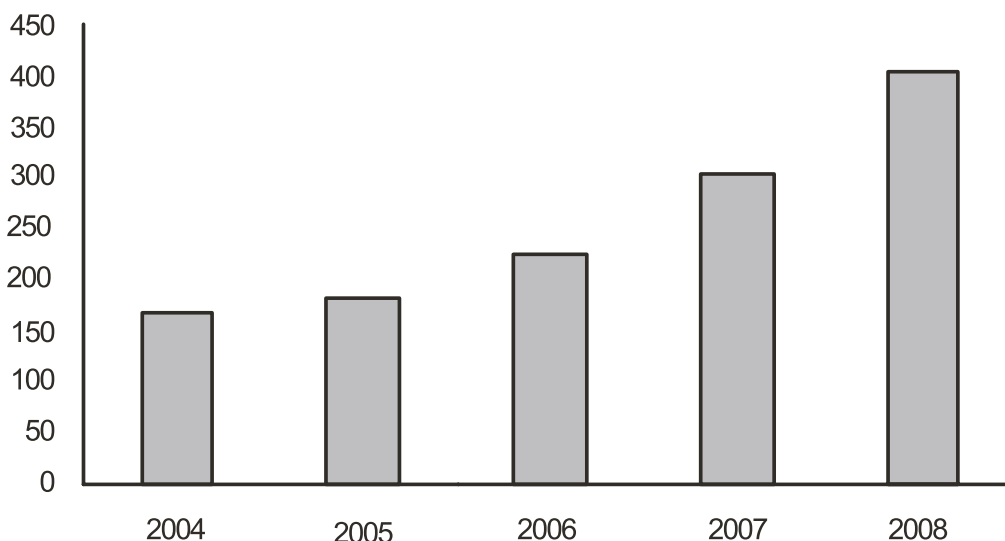


and magazines, such as *The Wall Street Journal*, *The Economist*, *Newsweek*, *Forbes*, and *The New York Times*. Moreover, a research attempting to quantify the use of the term “neuroeconomics” within scientists’ personal web pages shows that more than thousand scientists from many different disciplines use this word to describe their research interests (data-base Scirus).

The previous data prove that the rise of neuroeconomics is one of the most interesting scientific phenomena, not only for neuroscientists or traditional economists, but for philosophers interested in the dynamics of contemporary science as well. A great deal of interest about neuroeconomics is also due to the development of one of its sub-branches, i.e. *neuromarketing*. Research in neuromarketing investigates consumers' sensorimotor, cognitive, and affective response to marketing stimuli, measuring changes in their brain activity. In recent years many private companies, especially in US and UK, began to offer market counselling services based on neuroimaging analyses, concerning, for example, car preferences, the relationship between smells and colours of food products and the neural effect of advertising media delivering commercial messages (Lee et al., 2007). An example comes from a famous neuroimaging study applied to market phenomena (McClure et al. 2004) which tried to use an fMRI in order to explain behavioural preferences between two diffuse kinds of beverage.

The goal of this review is to identify the main features characterizing researches in neuroeconomics. More specifically, our attention will be devoted to the introduction of some recent experimental findings, showing how neurobiological research can contribute to economics. For this purpose, we will introduce some findings concerning the role of neurobiology for game theory analysis, focusing our attention on risk decision tasks, which represent a perfect case study for showing how neurobiological findings may cast new light on the role of emotional feelings during decision making. Understanding the neuronal mechanism underlying decision making might indeed allow economics to be built upon a more robust empirical domain and open up novel research directions which are yet unexplored.

In the next section we will start by introducing the main theoretical features characterizing neuroeconomics.



**Fig. 1** - Trend of publications that use both the terms “neuroscience” and “economics” (*ScienceDirect* data base).

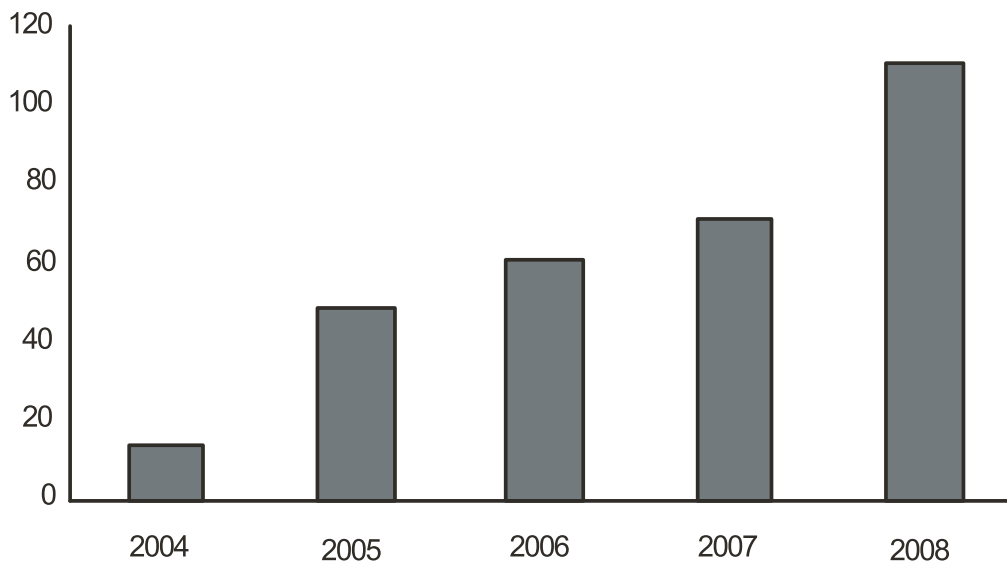


Fig. 2 - Trend of publications that use the single term “neuroeconomics” (*ScienceDirect* data base).

## 2. INTRODUCTION

For many centuries the study of the human social behaviour has been characterised by the implicit assumption that human beings can be conceived as *dis-embodied* beings. In the light of this assumption, contemporary social sciences have largely developed without paying attention to the underlying bodily mechanisms influencing social decisions. (Chorvat & McCabe, 2004). This is clearly the case for classical economic disciplines, which are based on the *idealistic* concept of *homo economicus*. According to this model, people interact as perfectly rational, unemotional and self-interest guided “maximizers” (Kenning & Plassmann, 2005) instead of situated social actors. Despite the copious insights of classical economical studies, the limitations of the *homo economicus* model are hard to ignore (Kenning & Plassmann, 2005). Many empirical studies have repeatedly shown that subjects frequently manifest *non-opportunistic* or *reciprocal* behaviours, as well as many other anomalies that are not predicted by the classical conceptualization (for an introductory review on anomalies in classical economics see: Camerer & Thaler, 1995). These studies have thus made it compelling the need to explore a radical revision of traditional rationalistic paradigms. In the last two decades economics began to seriously consider the insights coming from psychology. A new wave of economical studies, well represented by the rise of *behavioural economics*, emerged thereby (Thaler 1980; Camerer 2003; Rabin 2002, Camerer, Lowenstein, & Prelec, 2005). *Neurobiological studies* might represent today a new frontier to improve economical theories.

In our view *neuroeconomics* is the attempt to understand economy-related social behaviours by revealing the neurobiological mechanisms by which human decisions are taken. Differently from the two definitions introduced by Don Ross (2008) we conceive neuroeconomics as an extension of the empirical domain adopted by behavioural economics, aiming at *informing* research in economics with new data concerning the relationships between manifest behaviours and underlying neural processes. Thus, neuroeconomics doesn't represent the attempt to replace economics with neuroscience, instead it aims at offering new resources for a more complete understanding of human social interactions based on the adoption of a multidisciplinary stance.



Neuroeconomics can be considered a natural extension of *bioeconomics* (Gheslin & Landa, 1999). Whereas bioeconomics focuses on the ultimate causes of behaviour (evolutionary for example) neuroeconomics seeks to discover proximate causes of choice behaviour at the level of the anatomy and functional physiology of the human brain (Zak, 2004; Vromen, 2007). Following Glimcher & Rustichini (2004) we can say that neurobiological studies represent the ultimate element of a *discipline* which has the goal of providing a *multilevel* theory of human behaviour by relating three different contexts of analysis: the *economical*, the *psychological* and the *biological*. Neuroeconomics holds that the neurobiological analysis of social behaviour helps us understand what kinds of cognitive components are involved in decision making and may reveal unexpected structures of human mind that no behavioural study can show. Thus, understanding behavioural anomalies at the neural level might contribute to the development of a new theory of choice.

One problem is that, while economics is interested in idealised law-like generalisations, psychology is interested in concrete empirical contingencies. This difference is reflected in the fact that these two disciplines give a different meaning to the word “subject” which represents a pivotal element for both fields (Lowenstein et al., 2001). On the one hand, classical economics assumes that a subject is perfectly rational and absolutely impersonal, and that his goal is to obtain what he desires in the most efficient way. On the other hand, psychology is dealing with the empirical dynamics of a fallible subject whose behaviour is radically conditioned by many extra-rational influences. Thus, psychology and economics seem to be very different and hard to combine. But if we look deeper, we can see a strong affinity between them.

The idea that economics and psychology may advance with reciprocal advantages is not totally new. Indeed this insight was already well formed in the economical debate of the early 20's, as demonstrated by these words by Rexford Turgwell:

Man is equipped with the psychical and physical make-up of his first human ancestors; he is the sort of being who functions best in the exhilarations and the fatigues of the hunt, of primitive warfare, and in the precarious life of nomadism. He rose superbly to the crises of these existences. Strangely and suddenly he now finds himself transported into a different milieu, keeping, however, as he must, the equipment for the old life. Fortunately his power of reflecting (there seems to be an innate tendency to reflect and learn which is a distinguishing characteristic of our species) has enabled him to persist under the new conditions by modifying his responses to stimuli. (Turgwell, 1922).

Economics and psychology have two similar domains of research: they both study human behaviour. The progressive loss of *idealisation* in contemporary mainstream economics is caused by typical psychological results concerning the importance of emotions in decision making (Bechara et al., 2005; Deppe et al., 2005). In this context, the rise of neuroscience, with its abrupt methodological development (Kenning et al., 2005) makes it possible to have new insights about *extra-rational* influences in human behaviour, by introducing a new level of analysis, different from the one offered by a *purely psychological* discipline (Bechara et al., 2005; Smith et al., 2002).

When neuroeconomics started, the explanatory power of classical economics was in serious trouble because of the evidence concerning *conflicting behavioural preferences* and so-called *irrational decisions* (Schultz, 2008). During the late 90's several converging findings set the stage for the rise of neuroeconomics (Glimcher et al., 2008). For instance, Platt & Glimcher (1999) hypothesized that a decision model may provide a powerful framework for studying the neural processes that intervene between sensation and behaviour (Platt & Glimcher, 1999).



Yet, the collaboration between economics and neuroscience is having a more crucial impact on the former field rather than on the latter (Camerer et al., 2003, Camerer, 2008). For example, the typically neuroscientific idea that the brain works in a *parallel* rather than in a *serial* way has suggested that decision making is not a monolithic computation. Several neuroeconomical models have been trying to formalise such a distinction. For example, we can speak about the dualism between “hot” and “cold” ways of reasoning (Bernheim et al., 2004) as well as of the one between “deliberative” and “affective” systems (Lowenstein et al., 2004).

As noted by Camerer et al. (2005) in order to add value to economics, neuroscience has to suggest new insights and useful solutions to old questions. Neurobiological research in economics can point out commonalities between categories traditionally conceived as distinct. For example, mainstream economics considers the pleasure from obtaining money and the pleasure from drugs (or food) as two radically different phenomena, considering the first as an indirect value for the goods and services that it might produce. However, neural experiments show that the same dopaminergic reward circuitry in the mesolimbic system is activated by both drugs and money-related experiences (Montague & Berns, 2002; Schultz, 2002) suggesting that money provides a direct reinforcement that is independent from what people plan to buy (Camerer et al., 2005). Moreover, using event-related fMRI, Breiter et al. (2002) showed that gains produced predominant activation in the nucleus accumbens and hypothalamus of the right hemisphere, whereas monetary losses produce left hemisphere activity (especially in the amygdala). Findings such as these indicate that gains produce neural *rewards*, whereas losses provoke emotional responses associated with *fear* (Zak, 2004).

To add another example, neurobiology can challenge some of the most commonly accepted assumptions in economics such as the idea that a subject only strives to obtain what he likes. There is considerable contrary evidence from neuroscience and psychology that the motivation to perform an action is not always tied up to hedonic consequences. Thus, *want* and *like* may diverge (Berridge, 1999). So, as noted by Camerer et al. (2005) if we are not in the position to infer what people like from what they say they want, or from what they choose, then a different method for measuring subjective liking is required in order to avoid incorrect attributions.

### 3. LOSING RATIONALITY

It is a commonplace that people often take decisions under conditions of uncertainty, where they do not know the final outcome of their actions. Decisions under uncertainty look as if the subjects were choosing between *lotteries* or running a *bet*. It is thus all the more interesting to look for the mechanisms governing their choices. In this section we are going to focus our attention on this topic.

Economics typically explains decision making in terms of the so called “expected utility” model - EU model – (Bernoulli, 1738). According to this model, we choose between alternative courses of action by assessing the utility of all the possible outcomes, weighing it by the probability of their occurrence and then selecting the course of action that yields the greatest sum. In its classical form, the EU hypothesis claims that human beings take decisions by estimating these parameters as if they were engaged in an *explicit reasoning of declarative knowledge*. Yet, despite the great success of this model during the last century, this claim seems to be a limit of the EU theory. Over the last decades of the 20<sup>th</sup> century, research in neuroscience suggested that reasoning might be based on mechanisms that are – at least in part – different from those related to the production of propositional knowledge, so that such knowledge does not seem to be necessary. This insight has quickly become a cornerstone of neuroeconomics.



The evidence suggests a decision making model according to which we implicitly direct ourselves towards positive situations and far away from negative ones. Economists call this phenomenon “loss aversion” (Lowenstein, 2008). However, even if this model can account for several instances of our behaviour, there are some anomalies that still remain unexplained (see Starmer, 2000 for a review of such cases). In order to resolve this problem, the EU model was enriched by behavioural components (Thaler, 1980). The goal was to capture the fact that people tend to overvalue lower probabilities and undervalue higher ones. Once again, this modification was very useful, but it was not sufficiently strong. Indeed, even if this assumption contributed to solving many problems, there still remain many cases that cannot be accounted for in terms of a unitary mechanism, such as the one governing people’s reactions to gamble games.

An alternative explanation consists in replacing the EU model - even in its behaviourally modified form – with a model which threats *Risk As Feelings* (RAF hypothesis)(Lowenstein et al., 2001). According to it, decision making is divided into two parts: one is concerned with purely *rational* processes, the other with *emotional* reactions to risky situations. Focusing on the former part, it is possible to build a general interpretative model adaptable to every particular circumstance. On the other way, focusing on the latter, it is possible to build a more specific decision making model: according to this view, people could react in different ways to the same situation.

Close but different to the RAF model, there is the so called somatic marker hypothesis (Damasio, 1994). According to this hypothesis the decision making process encodes possible outcomes of alternative courses of action affectively. In such a way, decision making is influenced by some “somatic markers” coming from the computation of bioregulator values like, for example, emotions (Bechara et al., 2004). It follows that one of the hot spot of neuroeconomics research - maybe the hottest one – concerns the weight of emotional states upon the decision making process.

In next section we will show how the conception of rationality underlying the game theoretical framework used in social sciences can be criticized by looking at some relevant neurobiological findings, while an overall view of the relevance of emotional states in decision making will be provided in section 5.

#### 4. TRUST GAMES

Game theory is a part of applied mathematics that is largely used in economics to capture human behaviours in *strategic situations*, i.e. situations where the choice of an individual depends on the evaluation of the possible choices of others (von Neumann & Morgenstern, 1944). One of the main purposes of neuroeconomics is to provide a biologically based connection between functional and computational understanding of strategic choices.

We provide here a brief summary of some insightful findings concerning neurobiological studies on a paradigmatic kind of games called *trust games*. A typical case of trust game is the case where a player (the investor) has to decide how much from an initial endowment he should invest with a partner (the trustee) and where the partner has to decide whether to return money to the investor or not. If the trustee honours trust and returns money back to the investor, both players end up with a higher monetary payoff. However, if the trustee abuses trust and keeps the entire amount, the investor suffers a loss. The standard theoretic approach to this game predicts that a rational and selfish trustee should never honour the trust given by the investor and that a selfish investor who anticipates this behaviour will never transfer anything in the first place. This experiment mimics a vast number of real-life situations



characterised by monetary exchanges that take place in the absence of contracts enforced by a third party. Despite the predictions of the model, evidence from actual human behaviours shows that investors usually send amount of money to trustees, and that trust is frequently reciprocated (Sanfey, 2007).

Neurobiological evidence supports the hypothesis that trusting other individuals, by making *risky* investments characterized by the absence of any guarantee, is not a rational decision and it doesn't involve *only* the evaluation of monetary risks. An experiment performed by Kosfeld et al. (2005) shows that trust games also engage a complex social evaluation instead of only a monetary computation. Neurochemical results show that infusing the *synthetic neuropeptide oxytocin* in players of a trust game makes them more trusting than players in a control group and less fearful to be betrayed during social interactions. This effect is consistent with the hypothesis that oxytocin influences amygdala activity (Kirsch, et al., 2005) a brain region involved in *trustworthiness of faces* and processing of ambiguous events with *social implications* (Adolph et al., 2005; Hsu, et al., 2005).

In an fMRI experiment, King-Casas, et al. (2005) investigated correlations between area-specific hemodynamic variations within players in a *multiround* trust game in which the same two individuals (one defined the “investor”, and the other the “trustee”) played ten consecutive rounds. By adopting the multiround format in the game trust becomes *bidirectional*, so that both the investor and the trustee assume the risk that money might not be returned by the partner. A multiround version makes it possible to evaluate how reputation evolves during the time, as players develop models of one another through iterated exchanges.

The authors were interested in studying how cross-brain correlations might change as the game develops and the subjects built more accurate models of each other. The experiment was conducted under the hypothesis that specific parts of the trustee's brain should be correlated with the neural consequences of the investor's decision to trust, so that the investor's “intention to trust” would show strong cross-brain correlations. Results indicate that brain activity in the middle cingulate cortex (MCC) of the investor's brain and the anterior cingulate cortex (ACC) activity of the trustee's brain were strongly correlated, so that MCC of the investor was strongly active when the investor lodged a decision, and the ACC of the trustee was strongly activated as a reactive signal when the investor's decision was revealed.

Correlations measured during successive rounds showed a remarkable temporal transfer from the time immediately after the revelation of the investor's decision to the time immediately before the very same revelation, passing from a reactive correlation to an anticipatory one. The authors advanced the hypothesis that this shift is associated with the development of a model of the investor's intention to trust in the trustee's brain, figuring a typical *reinforcement learning process* in the context of a social exchange. Experiments such as this attempt to show how, in a multi-round game, trust becomes bidirectional and that social decision-making critically depends on internally represented models about the partners. Instead of only utility computation, experimental evidence indicates that trust-behaviours are dependent on repeated *social interactions* and *reputation-formation* (Fehr, et al., 2003).

Recently, Krueger et al. (2007) used an fMRI to measure brain hemodynamic variations while people interact with one another in a sequential trust game. In this experiment subjects were asked to make sequential decisions for monetary pay-offs such that the investor could either quit the game by not trusting the trustee, resulting in a small equal pay-off for both, or continue the game by trusting the other subject, hoping to receive a better pay-off. On the other side, the trustee was asked to decide whether to reciprocate the trust, determining a higher pay-off to both subjects, or defect the trust and keep all the money for himself. Results show that the brain regions involved in mentalizing processes such as the *rostrum medial*



*prefrontal cortex* and the *anterior insula* are commonly recruited for both decisions to trust and decision to reciprocate, supporting the hypothesis that trust games dynamics involves a *mentalizing process*, i.e. the social ability to represent another person's psychological perspective and intentions (Krueger et al., 2008).

Several other studies linking trust games with mind reading abilities were performed in the past ten years. An example is the experiment made by McCabe, et al. (2001) which shows that prefrontal cortex region, generally considered as the region subserving mind reading processes (Fletcher, et al., 2004) are more active when subjects are playing with a human than when they are playing against a machine following a fixed and known probabilistic strategy. This result supports the idea that decision making within trust games involves the adoption of a different subjective perspective and that it's not reducible to a mere utility computation.

Moreover, another fMRI experiment performed by Singer et al. (2004) shows that displaying the partner's face in a trust and cooperative game triggers brain areas usually associated with emotions such as left amygdala and insula. This result supports the hypothesis that seeing another person's face emotively influences the subject's representation for a future trust evaluation. This experiment confirms the study made by Winston et al. (2002) where subjects' hemodynamic variations in the brain were measured while they viewed faces and assessed each other's trustworthiness. Results showed that trustworthiness ratings were correlated with increasing activity in bilateral amygdala and right insula in response to faces judged untrustworthy. The authors argue that these results support the hypothesis that trust judgments require *automatic* and *emotive* evaluations, rather than *conscious* and *intentional* judgments.

Neurobiological findings thus suggest that trust games involve shared social systems and that human subjects use both *mentalizing* and *emotive* processes to understand the other players in the game. Even if some traditional studies do recognize a role for mind reading in economics (see Harsanyi, 1977 on the role of imaginative empathy for interpersonal utility comparisons) a perfectly *rational model*, based on the assumption of an *ideal utilitarian* subject, as well on purely introspective methods, seems to be inadequate to capture the real cognitive processes underlying decision making, otherwise involving emotive and mentalizing processes. Today, neuroscience makes it possible to cast a new light on old problem, by simultaneously vindicating the naive idea that "decisions dictated by reason are not always good, while decisions dictated by emotion are not always bad" (Frith & Singer, 2008).

## 5. THE INFLUENCE OF FEARFUL STATES IN DECISION MAKING

In this section we intend to analyse the way in which emotional states can interfere with decision making. One interesting aspect of this issue is whether the outlook of negative ending can elicit an emotional state and to what extent. For example Kahn (2002) monitored the brain activity by means of an fMRI, while subjects were playing a game against the experimenter. In order to win, players had to occasionally bluff their opponent, hazard getting caught and suffer a loss. As a result, experimenters found that the activation of the amygdala was higher in cases of "bluff" than in cases of "honest" games. These data become very clear if we consider that the amygdala - a subcortical area involved in elaborating the negative value of stimuli (Philips et al., 1997) as well as those areas linked to rewards (Murray 2007)- play a pivotal role in processing information related to fear (Le Doux, 1995, Le Doux, 1996, Le Doux, 2003) an emotion with a high defensive value (Phelps et al. 2000). Giving this value, fear is traditionally linked to a conservative behaviour, like monitoring the balance between outlooked state of



things and real consequences of our actions, as in the case of “bluff” conditions of the game proposed by Kahn (Kahn et al., 2002).

At the very beginning of the 21<sup>st</sup> century Knutson et al. (2001) had shown an activation trend similar to the one of the amygdala for the nucleus accumbens (NAcc) - an area of the ventral striatum. In a test in which the experimenters make the entity of the gain be variable, they noticed a direct correlation between the NAcc activation and the probability to earn higher gains: the higher is the value of this probability, the greater is the NAcc activation. Finally, it is well known that anticipatory activation of NAcc correlates with self-reported positive arousal, in line with the idea that NAcc has a key role in processing positive emotions related to rewards.

In the light of the RAF model, which gives a great relevance to the emotional dimension in the explanation of choice, it is easy to hypothesise that decision making in neurologically sane people is very different from the one of people with damages in cerebral sites involved in processing emotional information. In *Descartes' Error* (1994) Damasio claims that one of these sites is the ventromedial prefrontal cortex (VMPFC). Some years later, Bechara and co-workers (Bechara et al., 1997) subjected two groups - the former composed by people with a damage in VMPFC and the latter composed by neurologically normal persons - to a simple game test in which subjects simply had to draw a card from one of the decks in front of them. The card could be either positive or negative, i.e. it could cause either a gain or a loss. In this study, the ratio between gains and losses was such to make the subjects believe in a negative overlook. The result of this test was that, giving a negative extraction in a certain deck, people with damages in VMPFC restart to draw from this deck before neurologically sane subjects. In other words, people with lesions in VMPFC forget the negative event faster than those of the control group.

More recently, in Shiv and co-workers' work (Shiv et al., 2005) this experimental paradigm was modified into a set involving an advantageous game instead of a non advantageous one. This test consisted in a “heads or tails” game, but with one additional condition: there was a strong positive asymmetry between the value of gains and those of losses. Participants were recruited according to the presence of cerebral lesions in proximity of sites involved in processing fearful states. Assuming that fearful states have inhibitory effects upon our behaviour, it is reasonable to claim that people with damages in the fear-system will obtain more gains than people normally impressionable by fear. The study of Shiv provided a good empirical corroboration of this theoretical prediction.

Although there is a broad consensus upon the idea that loss aversion is functionally linked to brain regions involved in processing fear (Camerer, 2005; Trepel, 2005; Hariri, 2002) we should mention that this is not the only possible interpretation. To illustrate this point, consider the so called “endowment effect”, i.e. the phenomenon according to which people give a higher value to their objects than to objects owned by others (Thaler, 1980, Kahneman et al., 1990). Weber (Weber et al., 2007) combined an fMRI with the following test. The experimenters gave to the participants some mp3 songs, and the subjects had to decide at what price they were willing to sell these songs. Additionally, they were required to say how much they were willing to pay for other people's songs. The results were both behavioural and neuroscientific. Behaviourally, this study strengthened the idea of a ruling endowment effect. Neurologically, this study showed that the amygdala is more activated in the “sell” condition than in the “buy” one. Such result seems to be in line with the abovementioned ideas concerning the biological basis of loss aversion. Unfortunately, such an interpretation is not totally unambiguous. Indeed the words “buy” and “sell” are not synonymous of – respectively - “gain” and “loss”: a “buy” condition implies a loss of a things and a gain in money, as well as a “loss” condition implies a loss of money and a gain of things. Thus, the amygdala activation



cannot be explained only as a cause of loss aversion, simply because it is impossible to speak, properly, about a loss. Further investigations are required in order to solve this ambiguity.

Stronger evidence comes from the study of the VMPFC complex. For example Tom (Tom et al., 2007) combined a gamble test with an fMRI study in which the experimenters monitored the activity of VMPFC. In this game, the probability of a gain was equal to the one of a loss, while the entity of the gains was made run. The experimenters noted that the activity of VMPFC increased when the gain value increased and not after its decrease. On the other hand, Xue and co-workers (Xue et al., 2007, Xue et al., 2009) have focused their attention on the dorsal division of the prefrontal cortex (DMPFC) in order to assess whether there is a correlation between this brain region and decision making in unpredictable situations, i.e. those in which cues about behavioural endings are lacking. They found a positive correlation. In the light of their data, it is reasonable to conclude that the DMPFC processes information related to risk, whereas VMPFC seems to be involved in the elaboration of reward signals.

## 6. CONCLUSION

Despite encouraging findings, some of which introduced in this review, at present neuroeconomics should be still considered at its early stage. Today neurobiology is in fact characterised by different levels of knowledge. Some topics are largely explored - e.g. the abovementioned processes underlying emotions – while others are still at the beginning.

As this review shows, neuroeconomics does not imply the adoption of a reductive stance. That is, neuroeconomics doesn't aspire to reduce all form of economic behaviour to mere neural processes. Instead it aims at suggesting new empirical data for the development of future studies in economics. Knowledge about the underlying neural mechanisms can generate or substantiate hypotheses about what modulating factors influence social activities (e.g. the role of emotions in decision making) which in turn might be generalised in new theoretical behavioural descriptions. This makes it possible to reject the basic charge that neuroscience cannot influence economic modelling *in principle*, but shows how seemingly disparate neural and social sciences can collaborate.

Finally, we suggest that both further methodological analyses concerning the possibility of defining experimental sets mirroring effective economical dynamics, as well as a better discussion of procedures adopted in brain imaging studies, are required in order to increase the interdisciplinary prospective of neuroeconomics.

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