Real Academia
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Neuroeconomics: from homo economicus to homo neuroeconomicus

Discurso de ingreso en la Real Academia de Ciencias Económicas y Financieras leído,
el 15 de Mayo de 2008
por el Académico Correspondiente para Polonia

ILMO. SR. DR. D. JANUSZ KACPRZYK,

Y contestación por el Académico Numerario

EXCMO. SR. DR. D. MARIO AGUER HORTAL

Barcelona 2008

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Sumario

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Abstract. We briefly present the nascent field of neuroeconomics which may be viewed as a new emerging area of research at the crossroads of economics, or – more generally – decision making, and brain research. Neuroeconomics is about neural mechanisms involved in decision making and their economic relations and connotations. We review first the traditional formal approach to decision making, then discuss some experiments of real life decision making processes and point our when and where the results prescribed by the traditional formal models are not confirmed by what occurs in real life decision making performed by humans. We deal with both decision analytic type and game theoretic type models. Then, we discuss results of brain investigations which indicate which parts of the brain are activated while performing some decision making related courses of action and provide some explanation about possible causes of discrepancies between the results of formal models and experiments. We take into account knowledge about functions and roles played by those parts of the brain while performing tasks of a specific type, and while dealing with some feelings and emotions. We briefly indicate possible strengths of neuroeconomics and mention some reservations expressed by some researchers.

Keywords: decision making, economics, experimental economics, euroeconomics, brain, brain research, deliberation, emotion, affections.

1. Introduction

In this short article we wish to briefly introduce some new ideas related to the concept of neuroeconomics which is emerging as a new field of science at the crossroads of economics, or maybe – more generally – decision making, and brain research. Clearly, decision making is a "meta-problem" in our life which has been present since the very beginning of the mankind while brain research is a relatively new idea which has been gaining more and more popularity for some recent years, basically since the time when some advanced methods of brain exploration, imaging, etc. have become available. This combination of something "old" and "new" may certainly promise interesting results.

Let us start first with a brief account of the context within which we will be operating. The first question is: what is economics? We can clearly view it from different points and from different perspectives but it seems that for the purposes of this paper the following classic definition by Robbins (1932) should be appropriate and should provide a good point of departure:

"... economics is the science which studies human behavior as a relationship between ends and scarce means which have alternative uses..."

Notice that this definition, as short as it is, does summarize some very crucial issues. First, economics is a science with all the attributes of a scientific discipline, its specific tools and techniques, its paradigms, its scope of analysis and uses, etc. Second, economics is a strongly human oriented, even human centered science. Notice that human behavior, not wishful thinking or similar vagaries, is explicitly mentioned in this definition. Third, economics deals with scarce means, or resources, that can be used in different ways. It is quite obvious that the scarcity is crucial because if there is abundance, i.e. we can have for instance as much money, raw materials, time, etc. as we wish, there is no problem since whatever we do is admissible and good.

We can see at the first glance that in that classic definition of economics decision making plays a central and pivotal role. We deal with choice problems: how to use our limited means or resources to accomplish goals, satisfy some constraints, maybe even to do this in the best possible way, i.e. in the most efficient way, or optimally.

The definition of economics given above, which emphasizes the decision making aspect, has expressed what people have been aware of for centuries, since the beginning of the mankind, i.e. of the importance of acting rationally. Needless to say that this problem of doing the right (maybe the best) things is not only crucial in economics but exists in many fields of science and technology, notably in all application oriented areas.

This crucial problem of choice has clearly become a subject of interest of thinkers, scholars and scientists for many centuries, and even millennia.

Basically, the developments of science have always been motivated to a decisive extent by practical needs. Even if scientists and scholars have tried to understand some more general relations, functioning, etc. of their surrounding world, from the micro to the macro level and beyond, they have in virtually all cases been interested in finding solutions to intricate practical problems. Many examples can here be cited since the ancient times, as a need to solve problems of navigation, construction, logistics, accounting, etc.

A natural consequence of this interest of scientists and scholars has finally been an attempt to some sort of formal analyzes which should provide the analysts and decision makers with more objective tools and techniques. Mathematics has been considered a key tool in this respect and for good reasons because it has been able to provide powerful and "objective" paradigms and apparatus.

This trend has started very early but has gained momentum in the period between World War I and World War II, in particular after World War II. There are various reasons for this fact but, in our context, World War II has shown potentials and a great utility of a new field, operations (in the American form) or operational (in the British form) research aimed just at finding how to use scarce means and resources, that is how to find good (better or even best) decisions. A second reason was clearly the fact that World War II has resulted in a victory of the Allied forces but, on the other hand, has quickly triggered cold war characterized by a fierce military competition between the USA and the Soviet Union. Cold war has implied huge spending for science and technology that have resulted in an unprecedented growth of science and research in virtually all fields, including decision making and economics. This is a brutal truth: science and technology, including economics and decision making, has profited from the war and the subsequent cold war.

In this paper we will often speak about decision making but our analysis will certainly apply to a large extent to broadly perceived economics since for our purposes the very essence of decision making and economics is to choose a choice of action that would make the best use of some scarce means or resources that can be used in various ways leading to different outcomes.

Virtually all those early attempts at a formalization of decision making have proceeded in a normative or prescriptive context. Basically, quite a natural, yet simple conceptual framework has been assumed which has been viewed, on the one hand, as the one that follows intuition, and this is true to a large extent. On the one hand, this framework has often been considered as the one and only for a "scientific" approach to decision making. Notice that the latter aspect of considering any approach, tool or technique as "the one and only" is risky in general, and in particular in science because it may quickly be abandoned when new ideas prove to be effective and efficient. This will be the case in our case as well.

Basically, the point of departure for virtually all decision making models and approaches in the formal direction mentioned above is quite simple:

- The is a set of options, $X = \{x_1, x_2, \ldots, x_n\}$, which represent possible (normally all) choices of a course of action like: how much to invest: x_1 = EUR 1,000, x_2 = EUR 2,000, …, x_n = EUR 10,000., which car to buy: VW, Seat, Ford, …, etc.
- There is some preference structure over the above set of options which can be given in different ways exemplified by:
- preferences over pairs of options, for instance: $x_1 \geq x_2$, $x_2 = x_3$, $x_3 < x_4$, etc. to be read as: option x_1 is better (or, maybe, not worse) than option x_2, there is indifference between option x_2 and option x_3, option x_3 is worse than option x_4, etc.
- a preference ordering exemplified by $x_1 \geq x_3 \geq \ldots \geq x_k$,
- a utility function f: $X \to R$ (R is the real line but may be some other set which is naturally ordered like the set of integer numbers, the unit interval, etc.) such that if $x_i \geq x_j$, then $f(x_i) \geq f(x_j)$, for all i,j.
- a "natural" rationality is assumed which in the context of the utility function is expressed as to find such an optimal (best) option x* belonging to the set of options X which maximizes the utility function, that is:

find an $x \in X$ such that $f(x^*) = \max_{x \in X} f(x)$

Notice that at the first glance there seems to be no problem with this simple model as, indeed, we wish to find a best option which has a clear meaning. For instance, in the financial context when the utility function is income, we naturally want to maximize income.

These clear cut interpretations have implied that an agent operating according to such simple and intuitively appealing rules has been named a *homo economicus*, and virtually all traditional approaches to decision making and economics are in fact about various forms of behavior of a homo economicus.

Unfortunately, if we look more carefully then we can ask many natural questions. For instance, if we agree that preferences are something obvious in terms of what is a driving force behind the choice, while an utility function is something which is more convenient from a mathematical point of view to deal with, then what are the conditions under which a given preference structure can be univocally represented by an equivalent utility function? Without going into mathematical details, the answer is simple and dangerous, namely the preferences should be defined for all pairs of options, and the preferences should be transitive, that is if $x_i \geq x_j$ and $x_j \geq x_k$, then $x_i \geq x_k$, for all possible i, j, k.

These simple conditions have been considered so natural and obvious that virtually no researchers and scholars in the formal, normative or descriptive direction in decision making have been considering tricky issues related to what can happen if such a simple condition is not fulfilled.

This simple model has been a point of departure of a plethora of models and approaches which have been developed over the years. These models can be divided according to many criteria and aspects. For instance, we can extend these models to account for:

- Multiple criteria,
- Multiple decision makers,
- Dynamics, i.e. multiple decision stages.

On the other hand, we could use the classification related to those classes of problems which have triggered the emergence of some distinct scientific areas as:

• Optimization and mathematical programming,
• Optimal control,
• Mathematical game theory, etc.

which have shown their strength in so many areas and applications. A notable example is here control theory which has made it possible to control missiles or rockets in an incredibly precise way to hit very small targets from tens or even hundreds kilometers. We could see on TV that incredible, devastating hitting precision during the Gulf war or the Iraqi war.

Unfortunately, these successes of mathematical models of decision making, notably of optimization or control, have mostly happen in what might be called *inanimate systems*. These are systems in which a human being is not a key element though he or she can play some role. For instance, in the case of missile control a human perception of the very goal of control (to most accurately hit a target, maybe as fast as possible or with the least possible fuel consumption) is not crucial because it is somehow “obvious”.

The situation changes drastically when a human perception or valuation is an essential part of the problem, when we cannot neglect human characteristics like inconsistency and variability of judgments, imprecise preferences, etc. This is the case in virtually all so called *animate systems*.

We will concentrate in our next considerations on these types of decision making which concern animate systems in which a human being is a crucial element. Economics is clearly concerned with such systems.

If we look into the past, decision making has been an object of research for many centuries, and philosophers have been trying to find some general rules governing this important process. For instance, in the philosophy of mind, the standard view of decision making postulates that there is an equality between deciding and forming an intention before following a course of action (cf. Davidson, 1980, 2004). Some researchers have postulated that this intention can be equivalent to, or maybe inferred from or accompanied by, desires and beliefs. A natural consequence is that decisions which rational agents make are motivated by reason. Proponents of this direction assume that whatever decision we make, it should be rational and can be explained by some reason. Beliefs and desire can also be viewed to be inherent elements related to rationality because they justify rational actions.

Looking carefully at what we have mentioned before about the essence and main issues of economics, we can say the same about economics, i.e. that rational decision making is a core concept in economics as well.

Let us now mention two classes of decision making problems, viewed from the perspective of rational choice theory, which will be of utmost importance for our discussion: decision theory (or maybe better in our context – decision analysis) and game theory. Basically, they provide formal tools and techniques for determining optimal (in the sense of some specific criteria assumed) decisions in the context of individual and multiperson decision making. To be more specific, it should be better stated that the former one concerns situation with individuals and/or groups of individuals but when they operate without interaction in the sense of, for instance, responding to proposals. The latter one concerns decision making situations in which there are at least two individuals involved but there is an interaction between them like, for instance, a sequence of proposals and responses so that the individuals involve should take into account what their fellow decision makers can do.

First, let us look at the decision theoretic aspect and assume for simplicity that we operate in an individual setting. In this context, rational choice theory boils down to the construction if some logic of action. First, as we have already mentioned, we should specify which logical conditions are to me met to make decision making rational. A notable example is that the preferences must be transitive if we wish to use our model. On the other hand, if we take into account some chance mechanism (uncertainty), that is we have two parameters: the probability and the utility of consequences of the particular options, then a popular, considered obvious by many people approach is to multiply the probability of consequence of each option by its utility, and choose the option with the highest expected utility. From the point of view of the belief and desire model, probabilities represent beliefs while utilities represent desires.

On the other hand, game theory considers some individuals, at least two of them, making decisions in so called strategic contexts to be meant as that the preferences of at least another individual must be taken into account when a particular individual chooses an option (a course of action). We will call the individuals agents which is motivated by, first, a recent tendency to use this word in traditional human type gaming situations, and – second – because the same theoretic models have been employed for some time in many non-human type context, notably in the so called multiagent systems that are some type of sophisticated and complex software systems in which the role of individuals (agents) is played by (software) agents, special pieces of software which can operate independently, exhibiting even some sort of "intelligence". One should bear in mind that an individual or agent need not be physically a single person or a single piece of software. It can be a group of persons, pieces of software, or even organizational units if they can be viewed as uniform from the point of view that is relevant for our analysis.

In game theoretic situations decision making is represented as the selection of a strategy meant as a set of rules that govern the possible actions (options) together with their related payoffs to all participating parties (agents).

For example, in the famous *prisoner's dilemma*, two individuals, A and B, are criminals suspected of having jointly committed a crime. There is not enough evidence to have them convicted. The two prisoners are put into two separate cells in prison, and the police offer each of them the following deal: the one who implicates the other one will be freed. If none of them agrees, they are seen as cooperating and both will get a small sentence due to a lack of evidence so that they both gain in some sense. However, if one of them implicates the other one by confessing, the defector will gain more, since he or she is freed while the one who remained silent will receive a longer sentence for not helping the police, and there is enough evidence now because of the testimony of the defector. If both betray, both will be punished, but get a smaller sentence than if they had refused to confess. Notice that each individual (agent) has a choice between only two options but cannot make a good decision without knowing what his or her accomplice will do.

If we employed traditional game theoretic tools to find the optimal strategy for the two players, we would find that if both the players were rational in the pure or strict (and probably too trivial) sense, then they would never cooperate. Indeed, the "traditionally rational" decision making means that an agent makes decision which is best for him or her without taking into account what the other agents may choose. There is a rich literature on this topic and we can refer the reader to, for instance, Poundstone (1992).

There are many games of a similar nature and we will discuss some of them later in this paper as they are important for our discussion.

So far we have discussed decision making in the sense of what is "obviously rational" which boils down to the maximization of some utility function. However, on the one hand, this rationality is somehow like a wishful thinking, and we do not know if it follows what the people do while making decisions in real life. On the other hand, the basic models of decision making in both the decision analytic and gaming context have been surely developed by taking into account their solvability in both the analytic and computational sense. This is a very important aspect and is clearly reflected in all mathematical models that should be a compromise between complexity and "adequacy" and tractability.

So far we have been considering decision making in the sense of formal mathematical direction. But, it is quite obvious that this is just one of possible directions. Decision making, as an omnipresent meta-problem which is relevant everywhere, always and for everybody, has been a subject of intense interest in many different areas. This concerns notably psychology, sociology, cognitive sciences, and recently brain research. In the area of broadly perceived economics, we can mention here experimental and behavioral economics. We will now briefly review main aspects, issues and outcomes obtained in these areas by focusing on what may be important for our purposes.

It can be generally said that as opposed to approaches of the rational choice type mentioned above which focus on normative or prescriptive issues, virtually all those social science related approaches to decision making – which may be termed psychological for brevity – are rather concerned with the descriptive aspects. Basically, it is studied how subjects make decisions, and which mechanisms they employ. Maybe, and this sometimes happens, their patterns of inference and behavior can be viewed as an empirical counterpart to rational choice type approaches. For instance, well known works of Tversky and Kahneman and their collaborators (Tversky and Kahneman, 1991; Kahneman and Tversky, 2003, Kahneman, Slovic and Tversky, 1982) showed that decision makers' judgments and behavior deviate to a large extent from results derived by normative theories. Basically, agents tend to make decisions according to their so called "framing" of a decision situation (the way they represent the situation, for instance as a gain or a loss), and often exhibit "strange" loss aversion, risk aversion, and even so called ambiguity aversion. This all implies that their choices do not follow "obvious" results of traditional normative theories. A well known example is that agents usually prefer a sure gain of EUR 10 instead of a 10% chance of winning EUR 110, even if the second option has a higher expected utility.

Many psychological studies have also showed that people are not as selfish and greedy as the solutions obtained using tools of rational choice approaches may suggest. For instance, experimental game theory indicates that subjects cooperate massively in prisoner's dilemma and in other similar games, such as the ultimatum game or the trust game.

Let us briefly outline the essence of these games. The *ultimatum game* concerns a one move bargaining situation. There is a proposer, agent A, who makes an offer to a responder, agent B, who can either accept it or refuse it. Suppose that we are concerned with money and then A is to propose to split an amount of money at his or her disposal between himself or herself and agent B. If agent B accepts the offer of agent A, B keeps the amount offered and A keeps the rest. If B rejects it, both A and B receive nothing. According to game theory, rational agents must behave as follows: agent A should offer the smallest possible amount, to keep as much money as possible for himself or herself, and agent B should accept any amount just to have anything which is clearly better than nothing. For instance, if there is EUR 10 to split, A should offer EUR 1 and keep EUR 9, while B should accept the proposed split.

Unfortunately (for the traditional game theory but maybe fortunately from a different point of view), this is not the solution that is adopted by human agents in real life. Basically, most experimental results show that a "purely rational" game theoretic strategy is rarely played. People tend to make more just and fair offers. In general, proposers tend to offer about 50% of the amount, and responders tend to accept these offers, rejecting most of the 'unfair' offers which have been experimentally shown to be less than about 20%. So, agents seem to have a tendency to cooperate and to value fairness as opposed to some "greedy" behavior of traditional game theoretic approaches.

A similar situation can be witnessed in the so called *trust game*. In this game, agent A has an initial amount of money he or she could either keep or transfer to agent B. If A transfers it to B, the amount is tripled. B could keep this amount, or transfer it (partially or totally) to A. If we follow the solutions given by game theory, then either A should keep everything, or if A transfers any amount to B, then B should keep all without transferring it back to A.

Once again, unfortunately for the traditional game theory (but maybe fortunately from a different point of view), experimental studies have shown that agents A tend to transfer about 50% of their money and get more or less what they invest (cf. Camerer, 2003). What is worth noticing, experimental results for pairs of agents of a different sex, culture, education, age, etc. have generally shown a similar tendency towards fairness and cooperation, and not greed and disregard of other agents' interests.

To summarize, experimental approaches to rationality and how decisions are made by in real life by human beings can thus be informative for the theory of decision making, as they clearly highlight two features of practical rationality we follow in our life. First, our practical reasoning does not fully obey the axioms of either decision theory or game theory. Second, the traditional approaches which somehow neglect morality, fairness and consideration for other people might seem to be erroneously neglected in traditional formal analyses.

The above consideration provide us with valuable clues that some specific features of a human being should be taken into account in decision analytic and game theoretic models in order to obtain solutions that would be human consistent and hence would be presumably easier acceptable and implementable.

In recent years, however, there is another big boost to such deeper analyses of decision making in various context, both strategic and not, and this comes from brain research which has for some time become a rapidly developing area.

In general, the human brain has been and still is a great mystery but there has been a tremendous progress in recent years, and more and more is known about how brain operates, which parts of brain are responsible for which functions, etc. All this has been possible to a large extent due to a rapid progress in all kinds of equipment which makes it possible to visualize processes happening in the brain.

In the next section we will discuss how brain research can contribute to the development of economics. This new field, still at its infancy, is called neuroeconomics and seems to be able to open new perspectives and vistas[1].

2. Towards neuroeconomics

Even if we can clearly see that results obtained in the traditional decision analysis, game theory and economics are very strong indeed and have found many applications, we can hardy resist asking some more fundamental questions. First of all, all those models try to deal with a human centered act of decision making somehow from the outside, without a deeper insight. Namely, on the one hand, we observe how humans make decisions and try to find some rules (maybe

[1] Some inspirations to study neuroeconomics has been gained during the author's research visit at RIKEN Brain Science Institute, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan.

even rules of thumb) followed by the humans to arrive at a decision. We strongly believe that humans have accumulated over the centuries enough experience, knowledge and skills so that decisions reached can be quite good. On the other hand, in all kinds of prescriptive or normative approaches we try to conceptualize how a good (maybe optimal) solution should look like, then make an attempt to represent it formally in mathematical terms, of course taking into account that it must be solvable either analytically or computationally, or both, that usually implies simplicity.

Both these approaches are basically the same from the point of view of what is being observed and mimicked or what is being rationalized or even optimized. Namely, they both concern the behavior of an agent and/or agents in the sense of "externally visible" choices, courses of action, etc.

However, it is quite obvious that this externally visible behavior is just an implication or consequence of some more general mental processes that happen in our brain. One can therefore argue that what really matters is what happens in the brain not what is "externally visible" as a resulting behavior or resulting testimonies. It should therefore make much sense to look deeply into brain processes while investigating decision making and economics. Clearly, this concerns both the decision analytic and game theoretic aspects. This is basically the motivation behind, and the very essence of the new field of neuroeconomics. We will try now to briefly present the essence, main issues and problems, main tools and techniques and some results obtained in this new area which has been initiated some years ago, and one can cite Glimcher (2003), McCabe (2004) or Zak (2004) as representatives of pioneering works in which this new area has been proposed and advocated.

The first question that can be asked is: what is actually neuroeconomics? We have tried to briefly explain this above but an often cited definition is attributed to Ross (2005):

"… *neuroeconomics* … is the program for understanding the neural basis of the behavioral response to scarcity…"

Which obviously relates the main area of interest of neuroeconomics to that of economics (Robbins, 1932), that is to dealing with what to do when means and resources are scarce, like in traditional economics, but this time from the perspective of the neural system, that is the brain.

As in all areas of science, the first question is about how problems considered are selected and formalized, analyses are performed, conclusions are drawn. In neuroeconomics one can briefly outline the methodology which is employed as follows:

- Choosing a formal model of decision making and its related rationality, whether in a decision analytic or a game theoretic form, and then deducing what decisions the "rational" agents should make;
- Testing the model behaviorally, i.e. with respect to "externally visible" characteristics, to see if agents follow those courses of actions determined in the first stage;
- Identifying the brain areas and neural mechanisms that underlie the particular choice behavior;
- Explaining why agents follow or not the normative courses of actions mentioned.

These basic steps may be quite complicated and may include formal models or ensembles of them, maybe even less formal heuristic procedures, may concern issues which are not directly addressed by both decision analytic or game theoretic tools and techniques. Moreover, since we deal with human beings, we can perform analyses using a broad spectrum of individuals including people of various sexes, age, education, impairments, even handicaps or mental disorders.

Neuroeconomics proceeds therefore basically by comparing formal models with behavioral data, and by identifying neural structures causally involved in (maybe underlying) economic, or decision making related, behavior.

In neuroeconomics attempts are made to explain decision making as an implication or consequence of brain processes which occur in the representation, anticipation, valuation, selection, and implementation of courses of action (options). It breaks down the whole process of decision making into separate components which are related to specific brain areas. Namely, certain brain areas may perform (or maybe just decisively contribute to?) the representation of the value of an outcome of a course of action before decision, other brain areas may perform the representation of the value of a course of action chosen, and yet other brain areas may perform the representation of these values at the time when a decision is determined and is to be implemented.

The remarks given above are valid both for the decision analytic type and game theoretic type decision processes and we will now consider the consecutively from the neuroeconomic perspective.

Another class of tools needed by neuroeconomics is related to being able to discover what is happening in specific areas of the brain while an activity is being performed. This includes the tools and techniques for the following tasks:

- Brain imaging,
- Single-neuron measurement,
- Electrical brain stimulation,
- Psychopathology and brain damage in humans,
- Psychophysical measurements,
- Diffusion tensor imaging.

Brain imaging is currently the most popular neuroscientific tool. Basically, the main procedure is to obtain and then compare two brain images: when an agent performs a specific task or not. The difference detected can indicate that a specific area of the brain is activated during the performance of that particular task. There are many methods for brain imaging, but the following three are basic:

- The electro-encephalogram (or EEG), which is the oldest, boils down to the attachment of some electrodes to the scalp and then to the measuring of induced electrical currents after some stimulus,

- The positron emission topography (PET) scanning is an old technique but still useful and it measures blood flow in the brain which can be considered as an equivalent to neural activities,
- The functional magnetic resonance imaging (fMRI) is then newest and most often used method which measures blood flow in the brain using changes in magnetic properties due to blood oxygenation.

Though fMRI is the most popular and often considered to be the best, each of those method has some pros and cons; for details, see Camerer, Loewenstein and Prelec (2005).

Clearly, the brain imaging techniques mentioned above can not provide tools which would be able to see what is happening at the level of single neurons. Some very specialized methods exist for this purpose in which tiny electrodes are inserted into the brain, each measuring the firing of a single neuron. This technique is however invasive and restricted to animals.

Electrical brain stimulation is another method that can be used but it is again invasive and hence restricted to animals too.

A very important method in neuroeconomics is the study of what happens in case when some part of the brain is damaged or an individual suffers from a mental disease (e.g. schizophrenia) or a developmental disorder (e.g., autism). By observing differences in behavior between people who suffer and who do not suffer from these deficiencies, one can draw many interesting conclusions which may be relevant in our context.

One of old techniques is the measurement of various psychophysiological indicators like heart rate, blood pressure, galvanic skin response (e.g. sweating) or pupil dilation (e.g. in response to arousal, including monetary reward). These measurements are easy, fast and effective and efficient. However, their results may be sensitive to body movement, emotions, etc.

Diffusion tensor imaging is a new technique which uses the fact that water flows rapidly though myleinated (sheathed) neural axons so that the water flow can reveal the trajectories that project from one neural region to others which can be useful in understanding neural circuitry.

2.1. Decision analysis and neuroeconomics

The division of the decision making process into stages (set of options, a preference structure and it related utility, and a rational choice) is quite convincing as it is related to some results obtained in the studies of the very essence of rational behavior. For instance, Kahneman, Wakker and Sarin (1997) have advocated that the concept of utility should be divided in some subconcept which basically include:

- Decision utility which is very important, maybe even the most important, and refers to expected gains and losses, or cost and benefits,
- Experienced utility which has to do with the pleasant or unpleasant, or even hedonic aspect implied by a decision,
- Predicted utility which is related to the anticipation of experienced utility, and
- Remembered utility which boils down to how experienced utility is remembered after a decision, for instance it may take the form of regretting or rejoicing.

The concept of utility which is viewed in terms of such subconcepts is sometimes referred to as distributed utility. It is quite obvious that one can expect that this distributed utility can have close relations to some structures and processes in the brain. And, indeed, it plays a very important role in the field of neuroeconomics.

To give a simple example, the distributed perspective of utility can help explain more precisely why human agents exhibit loss aversion which has been confirmed by various psychological studies. To be more specific, human agents usually pay much more attention, or are more sensitive to a loss of EUR 10 than to a gain of EUR 10. Among some attempts at providing an explanation or justification, one can cite Tversky and Kahneman (1991) who attribute this loss aversion to a bias of a human being in the representation of the values of gain and loss. This is clearly somehow abstract and refers to some "externally visible" effects, and may need for the explanation some complicated cognitive processes. On the other hand, neuroeconomics explains loss aversion as an interaction of neural structures in the brain which are involved in the anticipation, registration and computation of the hedonic affect of a risky decision.

To be more specific, the amygdalae which are are almond shaped groups of neurons located deep within the medial temporal lobes of the brain play a primary role in the processing and memorizing of emotional reactions, and are involved in fear, emotional learning and memory modulation. The amygdalae register the emotional impact of the loss. The ventromedial prefrontal cortex, which is a part of the prefrontal cortex in the human brain, is usually associated with having a role in the processing of risk and fear. In our context, the ventromedial prefrontal cortex predicts that a loss will result in a given affective impact. The midbrain dopaminergic neurons compute the probability and magnitude of the loss, etc.

Agents are therefore loss averse because they have or maybe tend to have a negative response to losses (experienced utility). When they expect a loss to occur (decision utility), they anticipate their affective reaction (predicted utility). They might be also attempting to minimize their post decision feeling of regret (remembered utility). They anticipate their affective reaction (predicted utility). They might be also attempting to minimize their post-decision feeling of regret (remembered utility).

One may say that the midbrain dopaminergic systems are where the human natural rationality resides, or at least one of its major component. These systems compute utility, stimulate motivation and attention, send reward prediction error signals, learn from these signals and devise behavioral policies.

Similar investigations have referred to ambiguity aversion which has to do with the following phenomenon. If consequences of some courses of action are not sure, then the human agents exhibit a strong preference for risky prospects, that is those whose occurrence is uncertain but probabilities of occurrence are known, over ambiguous prospects, that is those for which the probabilities of occurrence are not known or are very imprecisely known.

A widely cited example in this respect is as follows. We have two decks of 20 cards each. There are 10 red cards and 10 blue cards in the first one (a risky deck), while there is an unknown proportion of blue to red cards in the second one (an ambiguous deck). Agents win EUR 1 each time they pick a red card. Though there is a 50% chance of winning in both cases, it turned out that human agents have a marked preference for the risky deck over the ambiguous deck. There is no reason for this preference if we assume that we proceed according to the rules of the traditional decision analysis. However, it has been shown that in the case of decision under ambiguity, a stronger activation is found in many areas, especially the amygdalae. Therefore, though in decision analysis ambiguity is viewed as a special case of risk, decision making under ambiguity and under risk are governed by two distinct mechanisms. Therefore, it is highly probable that ambiguity aversion occurs human agents have a stronger negative affective reaction to ambiguity than to risk. This is a very interesting result.

And, if we continue in this vein, we can see that one of the most robust finding in euroeconomics concerns the decision utility which is related to the calculation of cost and benefits (or gains and losses). Results of many investigations strongly suggest that this process is realized by dopaminergic systems. They refer to neurons that make and release the neurotransmitter called the dopamine. The dopaminergic system is involved in the pleasure response, motivation and valuation. The dopaminergic neurons respond in a selective way to prediction errors, either the presence of unexpected rewards or the absence of expected rewards. Therefore they detect the discrepancy between the predicted and experienced utility. Moreover, dopaminergic neurons learn from own mistakes: they learn to predict future rewarding events from prediction errors, and the product of this learning process can then be a bias in the process of choosing a course of action. What concerns the learning algorithms which can model neural mechanisms of such decision making processes occurring in dopaminergic systems, the so called temporal difference reinforcement learning algorithms are presumably the best choice (cf. Sutton and Barto, 1998).

As we could see, neuroeconomics can help explain many phenomena which have been noticed for years by many researchers while observing how decisions in real world are being made, and how their outcomes differ from those obtained from traditional models.

So far, the main contribution of neuroeconomics to decision theory may be viewed as giving more and more justification to the fact that decision makers are adaptive and affective agents. In other words, homo neuroeconomicus is a fast decision maker who relies less on logic and more on a complex collection of flexible neural circuits associated with affective responses. The utility maximization in real life and by human agents is more about feelings and emotions and less about careful deliberations. People tend to use emotions throughout the entire decision making process, and at the end tend to control their behavior toward the maximization of positive emotions and the minimization of negative ones.

The neuroeconomic view of individual decision making, and its related rationality, is therefore affective to a high extent. Notice that this is in a sharp contrast to a highly deliberative, "cold blooded" type process of traditional, formal decision analysis which concerns in virtually all cases decisions to be taken by and for human beings, whose behavior is governed to a large extent by affective and emotional factors. Clearly, neuroeconomics does not deny that deliberation is an important part of human decision making, it just indicates that this process alone is not adequate and sufficient to handle the crucial automatic and emotional processing.

2.2. Game theory and neuroeconomics

Now we will proceed to the game theoretic decision making context, that is we will basically be concerned with the strategic rationality. And again, most of the results obtained by following the paradigm of neuroeconomics mentioned in the previous section clearly suggest that strategic decision making is again a highly affection centered activity.

For instance, brain scans of human agents playing the ultimatum game indicate that unfair offers by the first player, denoted A in the previous section, trigger in the brain of the second player, denoted B, a "moral disgust". To be more specific, the anterior insula, which is associated with emotional experience, including anger, fear, disgust, happiness and sadness, has been shown to be activated in such situations of a moral disgust resulting from an unfair offer. What is interesting is that such activation is proportional to the degree of unfairness and correlated with the decision to reject unfair offers.

In the ultimatum game not only the anterior insula is involved but also two other areas of the brain. First, this is the dorsolateral prefrontal cortex which serves as the highest cortical area responsible for motor planning, organization and regulation. It plays an important role in the integration of sensory and mnemonic information and the regulation of intellectual function, goal maintenance and action. It should however be noticed that the dorsolateral prefrontal cortex is not exclusively responsible for the executive functions because virtually all complex mental activities require additional cortical and subcortical circuits which it is connected with. Second, it is the anterior cingulate cortex which is the frontal part of the cingular cortex that resembles a "collar" around the so called corpus collosum that relays neural signals between the right and left cerebral hemispheres of the brain. The anterior cingulate cortex seems to play a role in a wide variety of autonomic functions (for instance, regulation of blood pressure or heart beat) as well as some rational cognitive functions exemplified by reward anticipation, decision making, conflict recognition and empathy and emotions. In our context, when an offer is fair, it seems normal to accept it: there is a monetary gain and no aversive feelings. When the offer is unfair, however, the brain faces a dilemma: punish the unfair proposer, or get a little money? The final decision depends on whether the dorsolateral prefrontal cortex or the anterior cingulate cortex dominates. It has been found that anterior cingulate cortex is more active in rejections, while the dorsolateral prefrontal cortex is more active in the cases of acceptance. Thus, the anterior cingulate cortex, which is more active itself when an offer is unfair, behaves as a moderator between the cognitive goal (to have more money) and the emotional goal (punishing).

Needles to say that making a decision whether to accept or reject an offer in the ultimatum game is a complex compromise between multiple goals and values, a complexity that decision theory based on the traditional belief and desire type model can hardly cope with. We can however see again that the human behavior that can be observed in real life is well motivated by some crucial functions of some specific parts of the brain which are known to be involved in particular cognitive and other functions.

Some other "strange" types of behavior can be observed in strategic games when cooperation is really needed, and occurs in real life, but is not taken into account. For instance, in the prisoner's dilemma, players who initiate and players who experience mutual cooperation display activation in nucleus accumbens (accumbens nucleus or nucleus accumbens septi) which are a collection of neurons within the forebrain and are thought to play an important role in reward, laughter, pleasure, addiction and fear. Some other reward related areas of the brain are also strongly activated in this case.

On the other hand, in the trust game, where cooperation is common but again not prescribed by game theory, players are ready to lose money for punishing untrustworthy players or cheaters. And here again, it was found that both the punishing of cheaters and even anticipating such a punishment activate the nucleus accumbens suggesting that a revenge implies some pleasure.

To put it simply, all these results suggest that fairness, trust and cooperation are common because they have some generally accepted values. This is well reflected by activations of some specific areas of the brain but is beyond the scope of the traditional game theoretic approaches.

Another interesting affect that has been observed in this context is that all those emotions occur only in an interaction with fellow human players and have not been observed to any comparable extent during an interaction with computers. Human partners induce positive or negative emotions, while computer partners do not exhibit such affective reactions of a "warm glow of cooperation", "sweet taste of revenge", "moral disgust" or a simple unfairness type.

One can summarize these findings as follows. In the context of decision analysis and game theory neuroeconomics clearly indicates that money is not the only decisive factor as it is practically the case in traditional, formal approaches based on numeric utilities.

3. Conclusion

We have presented a very brief account of a new nascent field of neuroeconomics, mainly from the perspective of decision making, to be more specific: decision analysis and game theory, which is the pivotal element in any economic analysis and activity.

Our main line of reasoning has been to first mention some basic traditional mathematical models of decision analysis and game theory and then to briefly outline the very essence of results these models can prescribe.

Then, we have presented results of some experiments with the real human decision makers and shown how these results deviate from those prescribed by the traditional formal decision making and game theoretic models.

Finally, we have presented some results obtained by brain researchers which have shown relations between a stronger activation of some parts of the brain in real situations in agents participating in the decision making and games considered. One could clearly see that some effects which have not been prescribed by traditional formal models but can clearly be viewed as results of human features imply the activation of corresponding parts of the brain involved in or maybe responsible for the particular cognitive, emotional, etc. activities.

Neuroscience is clearly not only about "where things happen in the brain" or about showing that behavior is caused by actions in the nervous system which is obvious. In the long run the goal would be to discover the mix of affective and cognitive processes involved in economic tasks. Basically, for our purposes the main conclusion which can be drown from neuroeconomic research and experiments is that a human being is driven to a large extent by emotions, sense of fairness or justice, and is rather a fast decision maker. This is very much different than according to the traditional decision analysis and game theory. In their models and approaches the human decision maker is portrayed as a cold blooded, greed, inhuman agent for whom a sheer money type outcome really matters, and this is not fully confirmed by results of experiments with real humans and real life decision making processes.

Due to the basic character of this paper the scope and breadth of coverage is very limited. Moreover, the list of references if not very rich to increase legibility. For the interested readers we would recommend, first, some more basic and philosophical paper by Hardy-Vallee (2007), while for the readers who would need more detail, a broad coverage of main problems, issues, experimental results, etc. given in Camerer, Loewenstein and Prelec (2005). Both these papers contain a rich list of literature related to the field of neuroeconomics which have appeared in various journals, in many areas of science. Some criticism is, on the other hand, given by Rubinstein (2006),

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Discurso de contestación por el Académico Numerario

EXCMO. SR. DR. D. MARIO AGUER HORTAL

EXCMO. SR. DR. D. MARIO AGUER HORTAL

Excmo. Señor Presidente,
Excmos. Señores Académicos,
Excmos. e Ilmos. Señores,
Señoras y Señores,

La Real Academia de Ciencias Económicas y Financieras me ha conferido el honor de representarla para contestar en su nombre al sabio discurso de ingreso en ella pronunciado por el profesor Dr. Janusz Kacprzyk. La satisfacción que me inspira un encargo tan halagador va acompañada de mi propio goce por tener ocasión de expresar mi admiración a una figura excepcional de la ciencia europea, entregada a iluminar aspectos poco definidos de la misma, en cuyo empeño se ha convertido en una personalidad de excepcional prestigio internacional.

No se desprenderá otra cosa del rápido resumen que formularé enseguida de su biografía universitaria y los relevantes trabajos que jalonan cada uno de los puestos que ha venido desempeñando en su transcurso. Nos felicitamos todos de que nuestra Real Corporación haya podido integrar en su seno al profesor Kacprzyk, dentro de su propósito de abrir sus filas a los talentos económicos de cualquier nación y especialidad. Dentro de ello no nos complace menos que el país de nacimiento de nuestro nuevo académico sea Polonia, tan próxima a nosotros por numerosos vínculos históricos, culturales, espirituales y, actualmente, también industriales y comerciales, por todo lo cual la ceremonia de hoy reviste relevancia singular.

El doctor Kacprzyk cursó sus estudios en Varsovia, comenzando en el Departamento de Electrónica de la Universidad Tecnológica de dicha ciudad y siguiendo con un Master en Informática y Control automático. Se doctoró luego en Análisis de Sistemas en el Instituto correspondiente de la Academia de Ciencias de la capital polaca y en la misma recibió la habilitación de otro doctorado en Informática. Tras haberse laureado así en el estudio de la informática, la ciencia de sistemas y la automación, extendió desde finales del pasado siglo su interés por ampliar el dominio de estas y otras especialidades emprendiendo viajes científicos por Europa, Centroamérica y los Estados Unidos, en cada uno de cuyos centros actuó como profesor visitante en las áreas de informática y ciencias de la organización y de la gestión económica.

Es de destacar que en estos quehaceres y más tarde, al regresar a su patria, nuestro nuevo compañero fue interesándose por los aspectos más novedosos y creativos de aquellas ciencias, convirtiéndose en un destacado cultivador tanto del análisis de la incertidumbre como de la lógica borrosa y sus aplicaciones, así como de las decisiones tomadas bajo incertidumbre, áreas en que ha llegado a la cumbre constituyéndose en presidente de la Asociación Internacional de Sistemas Borrosos y de la Sociedad Polaca de Investigación Operativa y Sistemas. A la vez, pertenece a otras entidades de electrónica e informática y es profesor, por nombramiento del presidente de la República de Polonia, y académico de Ciencias de dicho país. Desde el año 1999 profesa en la Escuela de Tecnología de la Información de Varsovia cultivando sus temas favoritos de informática, inteligencia artificial, teoría de las decisiones y formación de bases de datos, especialmente las dedicadas a la incertidumbre.

La incansable actividad del profesor Kacprzyk no ha dejado de aplicarse a cuestiones prácticas diseñando sistemas de información en diversas industrias, colaborando en obras públicas, trabajando para Microsoft Windows y sumando esfuerzos al famoso International Institute for Applied Systems Analysis, de la localidad austriaca de Laxenburg.

El discurso de ingreso con que hoy nos ha favorecido nos presenta un ameno y sugestivo paseo por una temática muy actual, la neuroeconomía, que resulta del cruce de las ciencias económicas, la teoría de la decisión y la investigación cerebral, proponiéndose aclarar el funcionamiento de los mecanismos neurales que se implican en la toma de decisiones y sus relaciones económicas, con lo cual da un paso adelante cruzando la línea de la economía y planteando indicaciones sobre el metaproblema de las decisiones y su posible aclaración con la ayuda de la investigación cerebral.

Ciertamente, nuestro nuevo académico se incorpora al brillante y dinámico conjunto de estudiosos actuales que se interesan por los componentes cerebrales de las decisiones económicas, tales como Nestor Braidot, autor de *Neuromarketing, Nueroeconomía y Negocios*; Tim Harford, con su libro *La Lógica de la Vida: como la Economía explica todas nuestras decisiones,* o Dan Ariely, autor de *La Trampa del Deseo,* obras traducidas todas al castellano y editadas recientemente. En todas ellas, y otras, se toman en consideración los ingredientes emotivos, vitales, instintivos y demás que, al margen de la racionalidad, influyen en nuestras decisiones, tales como la preferencia por unos colores, la adhesión injustificada a una marca, la administración estocástica de nuestro dinero, que nos hace ser generosos a veces y calculadores en otras. Escribe Facundo Manes, profesor de Neurociencias Cognitivas, de la Universidad Católica de Buenos Aires que "si tuviéramos que racionalizar cada toma de decisión tardaríamos una vida". Otros autores señalan que solemos ser racionales en las decisiones sencillas e intuitivos en las abstractas. Numerosos experimentos efectuados en centros norteamericanos se resumen en la frase de George Lowenstein, de la Universidad Carnegie Mellon, de Pittsburgh, según la cual: "Bajo la influencia de emociones poderosas la gente hace a menudo lo contrario de lo que sería mejor para ella". No podemos detenernos a comentar que este criterio rige en nuestras elecciones de una marca, un establecimiento, un envase, una calle en vez de otra, y así sucesivamente.

Superando los abusos formalistas o prescriptivos de parte de las Ciencias Sociales anteriores, que tendían a enfrentar la conducta empírica con los procesos racionales, nuestro colega se suma a una valiosa bibliografía reciente para subrayar que los agentes económicos no obedecen siempre a la mera decisión entre una ganancia y una pérdida, sino que adoptan decisiones distintas en pos de la seguridad, del respeto a las costumbres, a la solidaridad con otros actuantes y a valores, en suma, extraeconómicos, apartándose de las conductas impuestas por la Teoría de los Juegos. De este modo unos investigadores de la Universidad de Stantford han experimentado la importancia de la presentación en dos menús idénticos, y de la forma y color de un producto y el epígrafe de que vaya destinado a personas deportivas o elegantes o sofisticadas, cual se ve infaliblemente en la perfumería y los productos cosméticos.

Todo ello muestra que las gentes no son sólo codiciosas o egoístas como se desprendería de las meras estrategias lucrativas, sino que tienden a la fantasía, las ilusiones, la colaboración social, la equidad, la concordia y demás virtudes poco provechosas.

Si estamos de acuerdo en este fundamento, nos será más fácil entender que la actuación económica se funda, según la definición de Riccardi, en "una combinación voluntaria de hombres que utilizan unos medios, dirigida a un fin y caracterizada por la existencia de un esquema de relaciones entre tales elementos" (*La dinamica della direzione,* Milan, ed. Angeli, 1958). Valoremos en esta definición el acento que pone en lo voluntario de la asociación de entes y las relaciones entre los mismos, creadoras de un conjunto sociológico.

De aquí se deriva la afinidad entre semejante conjunto, el concepto de institución social y el de sistema, proceso conceptual que hemos visto desarrollar brillantemente al recipiendario. Aunque esta vía de razonamiento se aparte de análisis económicos exageradamente formalistas, siempre podrá acudir a la ya venerable definición de Max Weber según la cual una organización consiste en "una categoría técnica que designa los modos en que los distintos tipos de servicio son combinados continuamente uno con otro y con los medios no humanos de producción".

Según escribe Guy Jumaire en su obra *Subjectivité, Information, Système. Synthèse pour une cybernétique relativiste* (París, L'Aurore/Univers, 1980):

> "La noción de información, generalizada si conviene en la de estímulo, está presente por doquier en nuestro derredor y constituye la motivación profunda sin la cual no habría evolución de los sistemas. Un sistema recibe información de su contorno y evoluciona, es decir modifica su estructura, en función de esta información.
>
> Se puede incluso hablar de información subjetiva, es decir *a priori*, y de información objetiva, o a *posteriori*. En efecto, cuando se observa un elemento que puede ser considerado como el más pequeño *quantum* observable y este elemento está aislado, la información que se tiene sobre este *quantum* apenas puede ser otra cosa que una información subjetiva; por el contrario, la observación del comportamiento de dos individuos entre ellos es una fuente de información, precisamente por las interpretaciones a que da lugar, y la información obtenida así es una información objetiva".

En otro pasaje de dicha obra el mismo autor señala:

“Todo sistema es por sí mismo una fuente de información absoluta que se transforma en fuente de información relativa en todo proceso de observación de la misma por un experimentador, lo cual permite caracterizar un sistema por su potencial de información relativista. El sistema evoluciona en orden a maximizar este potencial relativista; es decir la dinámica absoluta del sistema, si existe, es inaccesible al observador y sólo es físicamente significativa su descripción. Información y sistema deben ser definidos simultáneamente en sendas teorías duales y, de la misma manera que todo sistema está caracterizado a la vez por su interior y su exterior, la información se definirá por un aspecto interno y un aspecto externo.”

Y prosigue:

“Podemos afirmar que el problema del análisis de la economía mundial se remite más bien a la Teoría de Sistemas, e incluso a la Cibernética, que a una escuela matemática cualquiera, porque los modelos matemáticos no pueden abarcar más que los sistemas cerrados, mientras que los sistemas económicos, en cuanto que tienen diferentes observadores y actores que participan en ellos, son a la vez abiertos y cerrados. Esto es lo que convierte a la economía, en tanto que ciencia, en una que es extremadamente difícil”

Evidentemente, el deslumbrante viaje que ha emprendido nuestro ilustre correspondiente en Polonia no hubiera sido posible sin la amplia y variada formación que recibió y la extensión de sus actuales intereses en la investigación. En los Anales de nuestra Real Academia hará época el atrevido y sugerente viaje que el doctor Kacprzyk efectúa desde la Teoría de la Decisión a través de la Teoría de los Juegos hasta el profundo análisis neurológico del funcionamiento del cerebro humano.

Su propósito, brillantemente conseguido, estriba en la valoración de los aspectos cognitivo, emocional y otros que se entrañan en la actuación económica. De este modo, nuestro colega infunde una cálida ráfaga de humanidad al estudio teórico del quehacer económico. Este humanismo lo conecta encomiablemente con una apología de los aspectos emotivos, éticos y legales que participan en la toma de decisiones. Desechando el abusivo utilitarismo que a menudo ha caracterizado el análisis de las tareas económicas, nuestro insigne compañero hace valer que incluso los experimentos efectuados con cerebros humanos desmienten que los procesos de decisión en la vida real se guíen substancialmente por objetivos materiales. En esta directriz investigativa, el doctor Kacprzyk no se ha movido solo ni desentona del rumbo de reputadas corrientes actuales que respaldan lateralmente sus tesis, cual consta en la valiosa bibliografía que ha resumido al final de su discurso y que recoge trabajos de estudiosos actuales que se hallan en plena actividad, contribuyendo cada uno por su lado a edificar la neuroeconomía que nos ha bosquejado en la memorable jornada de hoy.

Esta nueva vestidura de la economía fundamental redunda en fomentar y difundir unos aspectos de nuestras ciencias tan nuevos e inspiradores como son el estudio de la incertidumbre como escenario económico y el examen de los conjuntos borrosos, temas ambos en que ha destacado nuestro querido presidente, el profesor Jaime Gil Aluja, cuyos trabajos demuestran que ambas áreas no son patrimonio de una escuela o país determinado, sino que son aplicables a toda actividad humana, igual que lo da a entender el discurso que ha pronunciado el recipiendario.

No sólo esto, sino que ambas especialidades parecen tener más porvenir y territorio que la teoría económica antiguamente formulada, que adolecía de soledad dentro de las ciencias y de una cierta rigidez terminal.

La introducción de la incertidumbre en el estudio y la praxis económicos salta por encima de cualquier limitación anterior y no conoce límite alguno, además de acercarse al carácter casual, caótico e indefinido que domina las tareas humanas y muy en especial las económicas.

En nombre de nuestra Real Academia me complazco en agradecer al insigne profesor polaco Dr. Kacprzyk la lección que nos ha ofrecido al ingresar en esta Corporación, y hago votos por que continúen las aportaciones que seguirá haciéndonos para contribuir al prestigio de nuestra Institución y al beneficio general de la ciencia económica.

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