Game Theoretic Economics in Neurodecisions

Author's Details:
[(1)]**Dr Madhubrata Satpathy,** Faculty, School of Economics, BJB Autonomous College, Bhubaneswar, India [(2)]**Col Prof Dr J Satpathy,** School of Management, Srinivas University, India and Management University of África, Nairobi [(3)]**Prof Sebastian Laza,** Executive Director, School of Applied Neuroeconomics, National University of Cuyo, Argentina
(All Authors are equi-contributing Authors and hence treated as First Authors)

Introduction

Most of our economic decisions end up being made more
from emotion than from cold
rational economic calculation, even if we believe otherwise".
…….. Marisela Cuevas

Following with concrete research results, we will mention the conclusions of other influential neuroeconomic papers. In The Neural Basis of Financial Risk Taking, Kuhnen and Knutson[i] tell us that financial investors systematically deviate from rationality when making their portfolio decisions, and in this way, in their study, they try to identify neural mechanisms responsible for such anomalies. Using fmri (neuroimaging), the authors examined whether, by anticipating investors' neural activity (i.e., By seeing what goes on inside their brain during decision making), optimal and suboptimal financial decisions can be predicted. They characterized two types of deviations with respect to the optimal investment decision (neoclassical): Risk Search Errors and Risk Aversion Errors.

As for the concrete results, it was found that activation of the nucleus accumbens (eminently emotional area of the brain, activated when the person has a marked preference for something) preceded both risky choices and risk-seeking errors, while activation of the anterior insula (part of the emotional brain, center of disgust-displeasure) preceded choices without risk and risk aversion errors. These findings suggest that:

- Different neural circuits, linked to anticipatory effects, promote different types of financial decisions,
- And, that excessive activation of these circuits can lead to investment errors (risk and search aversion).

In this way, they conclude that taking into account anticipatory neural mechanisms can add predictive power to the rational decision model of neoclassical economics, which evidently "remains in shame" in the face of empirical evidence.

Risk and Neuroeconomics

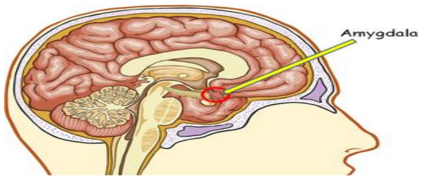
The management of money, and our emerging satisfaction or displeasure, would have much more to do with the unconscious than with the conscious, that is, much more with what is hidden in the iceberg, than with the part that emerges in sight, what that would imply a different treatment to the one we have been bringing in the last 02 Centuries"

…….. Marisela Cuevas

People react to risks at two different levels. On the one hand, people try to assess the objective level of risk that different scenarios have. But on the other hand, people also react - in situations with a certain degree of risk and uncertainty - on an emotional level, and such emotional reactions can greatly affect their behavior.

The existence in human beings of separate systems for the cognitive and the affective, which respond differently to the risks, is more noticeable when the two systems collide. People often seem to be "two minds" (one deliberative and one more visceral) when facing situations with risk: for example, when we have to invite someone to leave, or speak before a certain number of people, or take an important examination, our deliberative mind uses various tactics to propel us to take risks, which perhaps our visceral (emotional, non-deliberative) mind would prefer to avoid. Perhaps the most dramatic illustration of the separation of visceral reactions and cognitive / rational evaluations is found in the various degrees of phobias that people suffer: what distinguishes a phobia is the impossibility of facing a risk that one recognizes -objectively- be little dangerous (move by elevator, by an escalator, to name some of the most scandalous). Moreover, the fact that we humans spend some money on drugs and / or therapies to overcome our phobias, is a clear sign that our deliberative and visceral systems are not in mutual peace usually.

However, today there is much that is known about the neural processes underlying the emotional / affective responses to risks. Most of the risk-averse behaviors are caused by fear responses / fear of risks, where this fear seems to originate in the region called the amygdala (the center of fear, located in the emotional part of our brain). The amygdala constantly monitors new stimuli that indicate potential threat and responds to inputs from both automatic and controlled processes in our brain. However, the amygdala also receives stimuli from the cerebral cortex (the most rational part of the brain), which can moderate or even eliminate the emotional response.



A small limbic structure, dominated mainly by the amygdala, the insula and the nucleus accumbens, generates an automatic and almost instantaneous response to certain stimuli (for example, putting or not putting a certain product in the supermarket cart)…. However, in some decisions the slow system operates strongly, more deliberative, and more related to the frontal cortex, where the deliberative analysis of the action to be taken is given more force "

…….. Marisela Cuevas

The decision making under risk and uncertainty, as for example the case of intertemporal elections, adequately illustrate both the collaboration and the competition between the emotional and rational systems that exist within us. The case of the difference in risk taking between people with brain damage in the pre-frontal zone (which produces a disconnection between the emotional and rational systems) and normal people is much cited; the former always tend to make decisions that are much riskier than the latter. And while clearly, having pre-frontal damage to the brain in general decreases the quality of our decision-making, there are particular situations in which people with brain damage such as the above can make higher decisions than normal people, for example before very risky scenarios where normal people are usually paralyzed.

Emotions precede feelings, being like their raw material, and between the two they will be the guides that will allow us to make the decision, such as running away from that person who scares us, or not buying the product that we disliked because of its excessively high price, or its packaging, or, on the contrary, consuming certain goods and services in excess for the enormous pleasure it generates"

…….. Marisela Cuevas

The evidence from Neurosciences also substantiates the distinction between risk (known probability) and Knigthian uncertainty (ambiguity). Different studies with neuroimaging show that different degrees of risk and uncertainty activate different areas of the brain. For example, Ming Hsu and others[ii] found greater activation of the frontal insula and the amygdala (both eminently emotional zones) when people faced ambiguous choices (uncertainty) compared to risky ones.

Once again it can be seen that Neurosciences, and specifically, a consideration of emotional and automatic processes - both long forgotten by economists in dominant economic models - could potentially lead an important line of research and theory, argue Camerer, Loewestein and Prelec in his aforementioned paper[iii]. And they add that, if the current theory continues failing to incorporate the affective dimensions of risk, it will be unable to shed light on such important phenomena as the ups and downs in the stock markets, the betting markets and the vicissitudes of public responses to threats as diverse as terrorism and global warming, to name just a few important issues.

Game Theory and Neuroeconomics

We should begin to employ probabilistically based approaches to understand how the brain takes information from the outside world and uses that information in concert with stored representations of the structure of the world to achieve defined computational goals. It has been my central thesis that this goal can be best achieved through the synthesis of economics, biology and neuroscience. The central challenge facing neural scientist is to link comportment and brain. Economics was designed to be just that, a mathematical corpus which attempts to describe how any goal should be achieved in an uncertain world like the one we inhabit. Comportmental ecologist recognizes this; their field is focused on the study of how animals approximate economically defined goals with regard to the maximization of inclusive fitness. Experimental economics recognize this; their field is focused on the study of how economic comportment approximate economically defined goals with regard to the maximization of utility. Neurobiologist are also beginning to recognize this, and today it seems natural to assume that some form of Neuroeconomics will play a critical role in explaining how the brain of humans and other animals actually solve the maximization problems this two other disciplines have identified.

….. Glimcher

Game theory is an area of applied mathematics that uses models to study interactions in formalized incentive structures (so-called games) and carry out decision processes. Their researchers study the optimal strategies as well as the predicted and observed behavior of individuals in games. Apparently different types of interaction may, in fact, present similar incentive structures and, therefore, jointly represent the same game.

While economics was one of its first applications (especially for oligopolistic markets), game theory today is used in many fields, from biology to philosophy. It experienced a substantial growth and was formalized for the first time from the works of John von Neuman and Oskar Morgestern, before and during the Cold War, mainly due to its application to military strategy. Since the seventies, game theory has been applied to animal behavior, including the development of species by natural selection. In the wake of games like Prisoner's Dilemma, in which widespread egoism hurts the players, game theory has been used in political science, ethics and philosophy. Finally, it has also attracted the attention of computer researchers, using artificial intelligence and cybernetics.But punctually in the field of economics, Neurosciences in general and Neuroeconomics in particular are already well equipped to explore the main assumptions upon which the predictions of game theory rest. These assumptions are:

- Players have appropriate beliefs about what others are going to do,
- Have no emotions or concerns about what others earn,
- Plan forward,
- Learn from experience.

In strategic interactions (games), knowing how other people think, and also knowing how other people think you think, is critical in predicting other people's behavior. Nowadays, many neuroscientists think that in the human brain there is an area specialized in "mind reading" (also called Theory of Mind), probably in the pre-frontal zone of our brain, known as area 10 of Brodmann, which generates reasoning about what people who interact with us probably think and then do. In fact, autism is believed to imply a deficit in this area and related circuits. People with autism often have problems imagining what other people think and believe, and therefore are driven to have abnormal behaviors for the common people.

Mccabe and others[iv] used neuroimaging to measure brain activity when different people played games involving trust, cooperation, rewards and punishments. They found that those players who cooperated showed significant activation in the aforementioned Brodmann area 10 and in the thalamus. On the contrary, those who cooperated little did not show systematic activation in those areas. Also, interesting is the research by Tania Singer and others[v], who reported an important link between reward and behavior in certain games. These researchers, played the participants of their study, repeated games of the type "Prisoner's Dilemma", where some players, while they were scanned, faced a series of opponents. First, only the scanned participants were informed that some of their opponents would cooperate intentionally while others would cooperate, but unintentionally. Subsequently - also only the scanned ones - they were shown the faces of those against whom they had played. The faces of the intentional cooperators activated the insula, the amygdala and areas of the ventral striatum, among others. And since striatum is a brain area related to rewards, activations in this region meant that simply seeing the face of people who intentionally cooperated with one is retributive.

In an interesting work on the relationship between Neuroeconomics and Theory of Games, the Argentine economist Alfredo Navarro[vi] tells us that, apart from the importance that Neurosciences have for Economics -in particular to redefine the rationality hypothesis-, it is also important to keep in mind that there is a mechanism to export economic methodologies to neuroscience and biology, giving a new perspective to the theory of evolution and allowing analyzing the reciprocal behavior of living beings, where Game Theory plays a very important role. That is, according to this vision, there would be a round trip: Neurosciences impacting Economics, which gives rise to Neuroeconomics (the object of analysis of this work), but also, and this is the novelty, Economics impacting on Neurosciences That is, a soft science impacting a hard science. Let's see how this is. In what follows of this section we will make a review of the work of the aforementioned Navarro, which in turn is based on the very interesting work of the neurobiologist Paul Glimcher[vii], where this round trip between Economics, Neurosciences and Biology is analyzed.

Paul Glimcher, who comes from the field of medicine, not economics, in a recent work entitled: Decisions, Uncertainty and the Brain. The Science of Neuroeconomics, analyzes the behavior of living beings based on their effect on other living beings and of these on the first, trying to establish a new paradigm for a better interpretation of the behavior of living beings in general and of humans in particular. Glimcher, after reviewing the ideas about the nature of human behavior of Hippocrates, Galen, Harvey, Bacon and Galileo among others, considers Descartes (1596-1650) as the founder of neuroscience. Divide human behavior into two types, the simple and the complex. The first corresponds to the responses to the impulses of the environment, where there is no free will, as when we perceive the heat of a flame near one hand and quickly remove it. This was revolutionary, because no one before had seriously argued that a phenomenon as complex as behavior could be seen as the product of pure physical interactions in physiological systems. Nevertheless, the complex behaviors have as characteristic that they are at the mercy of the soul, which supposed lodged in the pineal gland, and that can decide freely according to the circumstances. While the first type of behavior is determined, as is the movement of the planets, whose trajectory we can foresee exactly, it does not occur as well as the second, where free will retains all its validity.

The idea that human behavior, at least that which we call simple, was perfectly predictable took more force at the end of the 18th century with the development of the mathematics of Leibnitz, Newton, Lagrange and Laplace, which allow to predict the future position of the planets every time with better precision. Why then not analyze the behavior of living beings with the same purpose of predicting their behavior? Charles Scott Sherrington, an Oxford neurophysiologist, at the beginning of the last century laid the foundations for the physiological study of reflexes, through a neat description of the processes, but still maintaining the Cartesian distinction between simple, deterministic behaviors and complex behaviors, not deterministic. Subsequently Pavlov generalized the analysis of reflexes to the totality of human behavior and therefore also generalized determinism to all human behavior.

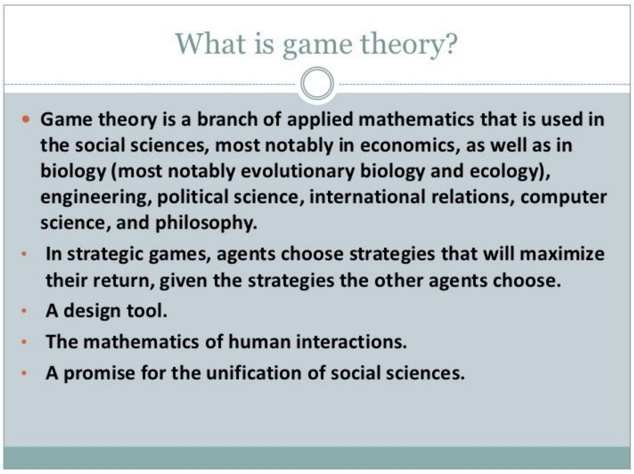
Several reactions against the Sherrington paradigm took place, especially that of Marr, who in the seventies proposed a different hypothesis: behaviors should be analyzed in terms of the organism's objective, which is basically to maximize their "inclusive fitness", meaning that rate at which genes are propagated. But to this must be added the fact that living organisms do not have a full knowledge of the world that surrounds them, for which reason they find themselves in a situation of relative uncertainty. The deterministic mathematics, which was the basis of the theories of reflexes, become insufficient, and it is necessary to resort to the mathematics of the uncertain, that is, to the theory of probabilities, since we rarely have a total knowledge of the circumstances around us. Although the theory of probabilities was born in the eighteenth century with Pascal and Bayes, three centuries pass until it is incorporated into human behavior, both in economics and in neurobiology.

In this way Glimcher, through his historical analysis, presents a way to analyze the behavior of organisms from two different perspectives: simple behaviors, in the Cartesian division, can be solved by applying classical economic theory, because either there is nothing random, or the uncertain is due to our lack of knowledge, so we must use the calculation of probabilities. But in other circumstances -complex behaviors-, we must resort to the theory of games, to analyze behaviors that are unpredictable, not because epistemologically we do not reach knowledge to explain the causes of behavior, as Pavlov maintained, but because they are, necessarily, intrinsically random.

This is a very striking statement for two reasons, firstly because it implies accepting that economic theory explains not only human behavior, but the behavior of all beings belonging to the animal kingdom, and not only economic behavior, but all kinds of behavior, and in second term because, to this affirmation, it is not made by an economist, but by a neurobiologist. According to Pavlov and Laplace, the uncertainty comes from the lack of knowledge of who decides, while what Glimcher says is that the uncertainty comes from outside, from the outside world to who decides, and that the latter must necessarily make a random decision if you do not want your opponent to predict your behavior and gain an advantage from it.

In this way, following the reasoning of the neurobiologist Glimcher, the analysis of the behavior of living organisms can be understood much more fully if we do so from the perspective of game theory, which we remember begins to be applied to the analysis of economic problems with the appearance of the developments of von Neumann and Morgenstern, in 1944, where non-cooperative zero-sum games are analyzed, but more especially after the Nash developments, which analyzes the determination of equilibrium in more generalized situations, such as games cooperatives and non-zero sum.

The analysis of the behavior of organisms that have brains allows Glimcher to argue that there are two types of uncertainty: one that we can call epistemological, which is originated in the lack of information and knowledge of the agent, and that could allow a mechanistic interpretation of the behavior, and another that derives from the need to follow a random behavior. Suppose a lion is in front of a lamb. You can jump to the right or to the left, trying to guess the behavior of the lamb. Suppose that it can also jump to the right or to the left. If it jumps in the same direction as the lion, it is lost, but if it does it in a different direction, it can be saved. If he always jumped in the same direction, the lion would know in advance what his behavior would be, and he would always be lost. But if he tossed a coin into the air to make his choice, he would be saved, for example, 50% of the time, all on condition that the lion does not know in advance what he is going to do. Therefore, random behavior is essential to pursue what has been defined above as "inclusive fitness".



In this way, the mentioned Glimcher reaches its conclusion[viii], in the sense that: “We should begin to employ probabilistically based approaches to understand how the brain takes information from the outside world and uses that information in concert with stored representations of the structure of the world to achieve defined computational goals. It has been my central thesis that this goal can be best achieved through the synthesis of economics, biology and neuroscience. The central challenge facing neural scientist is to link behavior and brain…’’

Glimcher’s Two - Stage Decision Model: Case Study

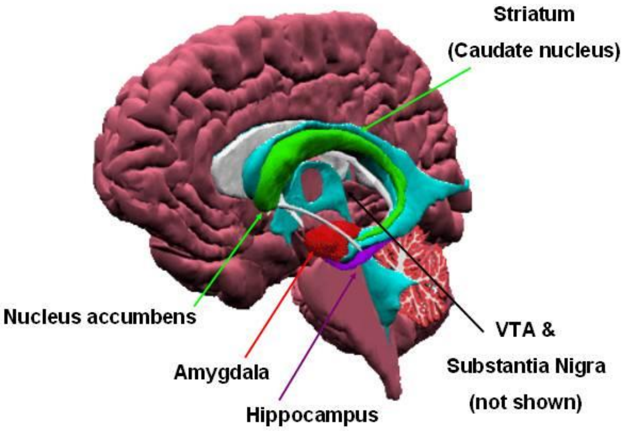
Economics was designed to be just that, a mathematical corpus which attempts to describe how any goal should be achieved in an uncertain world like the one we inhabit. Behavioral ecologist recognizes this; their field is focused on the study of how animals approximate economically defined goals with regard to the maximization of inclusive fitness. Experimental economics recognize this; their field is focused on the study of how economic behavior approximate economically defined goals with regard to the maximization of utility. Neurobiologist are also beginning to recognize this, and today it seems natural to assume that some form of Neuroeconomics will play a critical role in explaining how the brain of humans and other animals actually solve the maximization problems this two other disciplines have identified. In short, Alfredo Navarro, in his great review on the work of Glimcher, illustrates us about something that should fill us with pride to who we come from a soft science such as economics: we are in a position to export analytical tools to tougher sciences such as neurobiology, since it has been discovered that, for example, Game Theory, is a very useful resource to understand the behavior of a large part of living beings, and not only of companies in their economic interactions (such as the theory of Oligopoly).

Paul glimcher, maybe the most important neuroeconomist of the planet at present, from his laboratory at new york university, has made numerous experiments and collected huge empirical evidence about studies done in other parts of the world, which has allowed him to condense all this material into an interesting theoretical model, published at initial version in 2009[ix], then reactualized, where it is hypothesized about the true functioning of the human brain when making decisions. Here is a summary of his model, which in turn is a brief summary of much what it is known in neuroeconomics so far:

- This model of glimcher is called "two-stage", because on the one hand, the assessment aspect of decision alternatives is analyzed (something similar to the utility that people give to each object or possible action) -the valuation map- and on the other, the concrete decision to be taken is analyzed, that is, the reason for the selection of a single one (among several alternatives) and its subsequent execution -today decision-;
- To give a simple example, in the assessment stage, the model describes the neuropsychological circuits through which human beings value the alternatives a, b, c, d and e that we have for a given course of action (for example where to go on vacation next summer), that is, something similar to the utility (the economic concept) that we give to each alternative in the neoclassical model; whereas in the decision stage, the model describes in what way (brain circuits that are activated) we end up choosing the "supposed" best alternative, say a, to go on vacation;
- The assessment stage has been studied in more detail and depth in recent times, not so much the decision stage, which in humans is a bit delayed (but not in other mammals, such as monkeys), mainly due to the fact that (in humans) the temporal dynamics of the selection and execution of a given course of action today is difficult to follow via neuroimaging (FMRI);
- In any case, the aforementioned "two systems or stages", valoration and decision, would not be watertight behavior, since there is some empirical evidence that some characteristics of our valuation process (our preference function) are intrinsically attributable to mechanical processes linked to the decision stage;
- In another interesting feature, today a high number of studies shows that certain areas of the ventral striatum and the frontal cortex "learn" and "represent" valuations (preferences) even when "learning" is passive, that is, even when the person is not faced with an action or specific object on which he has to decide;
- The values (preferences) assigned to objects and actions would be "learned" by means of "trial and error", where the dopaminergic neurons of our mid-brain would play a fundamental role, through the concept of the reward prediction error (the difference between the expected reward of a given course of action and the one

actually achieved), an error that would be narrowing down more and more thanks to the aforementioned "learning";

- The decision system involves large portions of our parietal cortex, among others; that in turn receive direct and indirect projections from the areas of the assessment system, and, once the decision has been made, the process is projected directly towards the movement control areas, for the concrete execution of the decision;
- In a fact that is quite limiting for those theorists on welfare issues, in neurosciences today we know a lot about the neuronal circuits involved in the aspects of evaluation of alternatives, only one little about making concrete decisions, but almost nothing about the neural circuits that act in what is called a person's "sense of well-being"; since as we all know, not necessarily the fact of consuming (even though there is a sharp process of weighing rewards and punishments, or costs and benefits) leads us safely to a feeling of well-being;
- In something that is very important, in neuroeconomics the concept of "subjective value" (vs) is proposed, but in cardinal form, instead of the traditional concept of "utility" of the traditional theory, which is ordinal;
- The vs, in this way, being cardinal, is measured in terms of the rate of "firing of neurons" -neuronal firing rates- that occurs in certain areas of the brain before the perception of each object or alternative action to choose (for example the options a, b, c, d and e to go on vacation), where the researchers analyze said "neuronal ignition" from the scan of our brain, via neuroimaging;
- The choice of the final alternative when making a decision (the alternative a to go on vacation), would be given after comparing the relative vs between the different options, after a "fouling" of the process by "noise";
- The "reward prediction error" -rpe- of a chosen alternative would be given by the difference between the expected vs and the vs obtained when making the decision (for example, alternative a to go on vacation); and through the delimitation of said rpe is how our brain would improve its rating system, in this way, it is getting less and less wrong;
- The empirical evidence (and working hypotheses) available today suggest that two brain areas seem to contain all the neurons required to extract vs for any object and action: the ventral striatum (member of the limbic-emotional brain) and the middle prefrontal cortex, and in particular the ventral striatum for actions and the middle prefrontal cortex for objects;
- But one thing is the extraction of sv (that is, granting value to options a, b, c, d and e before making the decision) and another one its storage (once the decision to choose a has been made), the purposes of being used in subsequent decisions;



- In this way, the SV calculated in the areas mentioned in the previous item would be stored in a much wider area than the ventral striatum and the middle prefrontal cortex, which we had seen almost exclusively involved when SV is granted for the first time to an option;
- Which would lead to the conclusion that when an SV (already stored) is represented in our brain (for example, when deciding where to go on vacation next year, not this year), it would reflect activity in areas

such as the lower frontal sulcus, the insula, the amygdala, the posterior cingulate, the superior temporal sulcus, the caudate nucleus, the putamen, and the dorsolateral prefrontal cortex, and obviously the ventral striatum and the middle prefrontal cortex; that is, a much wider area than the participant in the initial assessment of the option;

- However, and in what is a current limitation of neuroeconomics, the details (i.e. The how, not only the where) of this assessment process -assignment of vs to objects and actions- are just beginning to be understood, since they are difficult to reach via neuroimaging;
- Going to the decision stage, and as we said at the beginning, it is much less studied than the stage of evaluation, always speaking of human beings, not of other mammals, like monkeys, where the empirical evidence is much greater;
- In the decision stage, the neurons of the lateral intraparietal area (lip) would seem to play a fundamental role, since they would be responsible for representing the relative vs of each decision alternative (the a, b, c, d and e of our example of holidays);
- Remember that the vs of each alternative comes from the assessment stage, and arose basically from the neuronal activity of two specific areas: the ventral striatum and the middle prefrontal cortex; but in the decision stage, the absolute vs of each alternative decision would be transformed into relative vs, and this would occur first in the posterior parietal cortex and then be represented in the lip area;
- As in the assessment stage, in the decision stage there is also internal brain "noise", which affects the quality of decision-making;
- At a certain moment, the set of available options (a, b, c, d and e, with their respective absolute and relative vs) converge to a single alternative, the one chosen (alternative a), which would occur when collicular neurons they exceed their "trigger threshold";
- In what is a very important current limitation, it should be mentioned that the majority of these studies on the decision stage revolve around monkeys, and in particular decisions made through "generation of movements through the eye", which is not the only possible alternative to generate movements. However, always according to Glimcher, there is some empirical evidence that this type of brain structures would also operate for decisions on more abstract objects than those that a monkey can usually choose (and which are more usual in humans); and less evidence that it would also operate for structures that generate movements other than the eye, in both monkeys and humans; clarifying that the "lesser evidence" available is temporarily, especially with the advances that are coming in neuroimaging.

***Single or dual system*?**

To finish with this impressive model, and as we said at the beginning, glimcher polemizes with kahneman and affirms that the output of the assessment stage is not only input of the decision stage, but also the reverse path would be observed, since there would be numerous decision circuits interconnected with important areas of assessment, such as the aforementioned frontal cortex and basal ganglia; that is, the process would not be linear or additive, but rather more complex, but unitary.

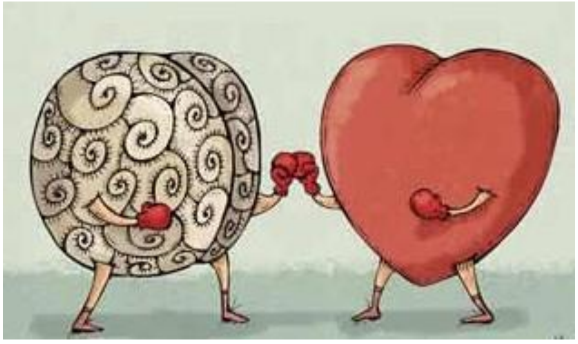
In fact, Glimcher, at the end of the exhibition of his model, attacked fellow neuroeconomists and behaviorists, such as Nobel prize winner Kahneman, Laibson or mc lure, who proposed the existence of two relatively independent systems that would regulate decision-making, one associated with the emotional (the limbic area) and the other more rational (some of frontal and parietal cortex).

To be more specific, Glimcher criticizes the "multiple ego" rationality models, which generally describe the area comprised by the basal ganglia and the prefrontal mid cortex as an emotional module, which interacts (additively) with a second system organized around the posterior parietal cortex and the dorsolateral prefrontal cortex, which would form a rational module.

The mentioned Glimcher indicates that, for example, it would be relatively proven (in monkeys) that neural activity in the posterior parietal cortex (eminently rational) would predict preferences (supposedly generated in emotional areas), under all the conditions that have been studied (immediate reward, future reward, large and small rewards and rewards of high and low probability). And later Glimcher mentions a lot more empirical evidence, that together, they would be showing a structure globally involved in valuation activities (stage of assessment) and not a structure managed exclusively by emotionality;

Of course, concludes Glimcher, the emotions truly influence our decision-making, especially in the assessment stage, but in no way would there be "multiple selves", that is, the emotional on the one hand determining valuations (utilities) of objects and actions, and the rational on the other side, deciding which is the best option and giving the order to execute.

And here it is convenient to cite the criticism of Kahneman[x], the Nobel prize in behavioral economics, who does not believe that the evidence cited by Glimcher is conclusive to invalidate the argument that decision-making emerges from a conflict between emotions and reason; the opposite of the "unitary" system proposed by Glimcher;



In fact, always according to Kahneman, there would be important behavioral evidence (more grounded in psychology than neurosciences) about the existence of "multiple selves" in our psyche, and the importance of conflict; however, he concludes that more empirical evidence is needed from neurosciences to define the winner of this debate; that is to say, it does not attack in definitive form against the Glimcher model, which is logical, since the evidence in neuroscience is superior to the psychological one. Finally, Glimcher acknowledges that there are still important aspects to better specify in his model, basically due to lack of empirical evidence, especially in the decision stage, since we remember that neuroeconomics is just touching the decade of life and can still be improved a lot plus the instruments available to open our "black box".

In summary, neuropsychological system that sustains our decision making would seem to be a "little bit" more complex than the simplified version of neoclassical economics, based on ordinal utility curves, faced with the restriction of the income of each consumer, to be able to determine what quantities are consumed of each good and service, deriving from this model the respective demand curves of each of them.

Inter - Temporal Decisions

Economic analysis defines intertemporal decisions as those with consequences over multiple periods of time, including a wide range of decisions, of varying degrees of complexity and frequency, such as investments in real and financial assets, savings for retirement, purchases with credit cards, purchases of merchandise for the home in advance, etc.

Traditional Model

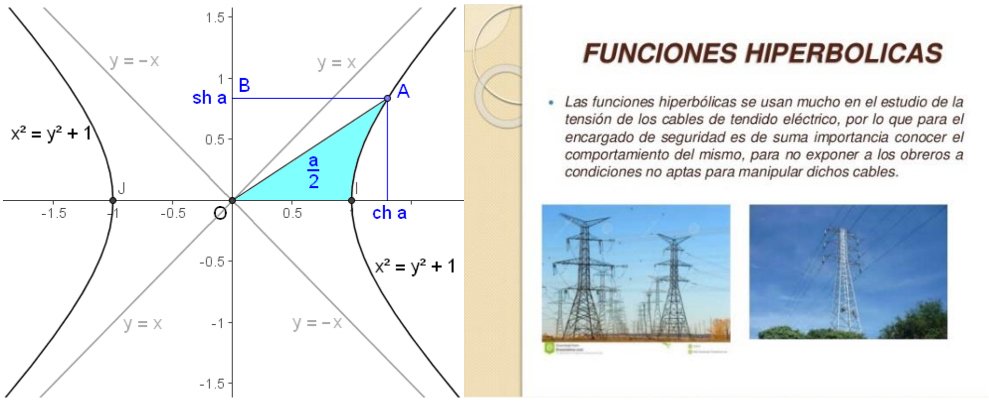
To study and model intertemporal decisions, traditional economics has generally used the theory of discounted utility, based on the idea that economic agents prefer a similar reward more if it is obtained in the present than in the future; and similarly, future costs would be less painful than the costs to be faced today.

To formulate these theories, models have been generally used based on the assumption that the total utility of a series of rewards and / or costs over time can be decomposed into a weighted sum (or integral) of utility flows in each period of time. A particular case is the function of exponential discount, which has as its main characteristic that the discount rate is independent of the passage of time, and consequently, the evaluation of a course of action towards the future (project) is independent of the moment in which the project is analyzed. This property of decisions is called dynamic consistency.

However, the problem with this exponential model is that it cannot explain several empirical regularities, that is, it would be incompatible with reality in certain cases. In fact, several field studies show that discount functions decline at a faster rate in the short than in the long term, that is, people are more impatient when they make short-term exchanges (today vs tomorrow), than when they make exchanges in the long term (day 100 vs day 101). To illustrate, the empirical evidence suggests that if a person is given $ 100 to choose now or $ 110 tomorrow, he may prefer $ 100 now, while the same person may choose $ 100 in two years or $ 110 in two years and one day, he could prefer $ 110 in two years and one day. It seems then that discount rates tend to be higher in the short term than in the long term.

Alternative Approaches

At present, some economists familiar with the neuro have studied alternatives to exponential discount functions. The generalized hyperbolic function has the property of declining at a higher rate in the short term than in the long term, adjusting the cases of inconsistent decisions. Ainslie (1992)[xi] and Loewenstein and Prelec (1992)[xii] have used this type of function in their studies.



Another highly studied discount function is also the quasi-hyperbolic discount function, which also captures the property that the short-term discount rate is high and the long-term discount rate is low. The quasi-hyperbolic equation is generally referred to as the function biased to the present and was first proposed to model the planning of the transfer of wealth between generations, and then applied to an individual scale by David Laibson (1997)[xiii] in the model of the golden eggs to study intrapersonal financial decisions.

These models would better capture the dynamic inconsistency of the preferences, that is, the idea that the passage of time changes the preferences of the agents and, consequently, projects that can be positive evaluated with some initial time perspective can be turn negative if they are evaluated from other time perspective. Also models of dynamic inconsistency have been used to study problems of self-control: credit card expenses, drug addictions, etc.

Neuro Fundamentals

As noted above, the quasi-hyperbolic function of discounting time provides a good fit to experimental behavioral data, however few studies have focused their analysis on identifying the causes of this tension between short-term and long-term preferences. Then the following questions arise:

- What is the mechanism behind these intertemporal decisions?
- Do they arise from a single preference mechanism or from multiple systems that interact?

Dopamine and Consumer Pleasure Center

Dopamine area is considered as 'pleasure center', since it regulates motivation and desire and causes us to repeat comportments that provide us with benefits or pleasure. It is released with both pleasant and unpleasant stimuli, causing us to demand more of something, or to avoid them if the result is unpleasant. It is very studied also in the case of addictions. Its objective is clear: to make us want to repeat one or more comportments, as a way to assure existence. For example, the pleasant sensation we feel when having sex or eating something delicious, make us want to repeat the action, ensuring the survival of the species through the reproduction and / or consumption of food. That is to say, for Economics, dopamine is of vital importance, being one of the main responsible for modeling the consumer's preference curves, and the whole valuation-pricing system of the economy.

Neuroeconomics shows today that the unconscious basis of comportment, highlighted by Freud, connected to the dopamine centers of pleasure or cerebral reward, are not far from the economic reality, and today large corporations are designing real experiences of pleasure for its consumers, generating a truly Freudian paradise of high added value for companies, which at some point will lead governments to assess how much danger they represent in terms of purchase addictions, but that today represent great profits for companiesThat is, we live clearly today in a world where, thanks to Neuromarketing, corporations are learning to find product mixes that give maximum sensory enjoyment to the consumer (visual, tactile, auditory enjoyment, etc.), generating a true Freudian Economy, in the sense of enjoyment and pleasure, not repressed this time.

The cerebral reward system, around the ventral striatum and the nucleus accumbens (limbic system), where the neurotransmitter king is dopamine, is key in this process. It turns out that this neurotransmitter influences the sensation of pleasure in the brain, and therefore, shapes the tastes and preferences of consumers. Its secretion increases during pleasant situations and stimulates one to look for that activity, occupation or pleasant goods and services. Its objective is clear: to make us want to repeat one or more comportments, as a way to assure existence. For example, the pleasant sensation we feel when having sex or eating something delicious, make us want to repeat the action, ensuring the survival of the species through the reproduction and / or consumption of food. That is to say, for Economics, dopamine is of vital importance, being one of the main responsible for modeling the consumer's preference curves, and the whole valuation-pricing system of the economy.

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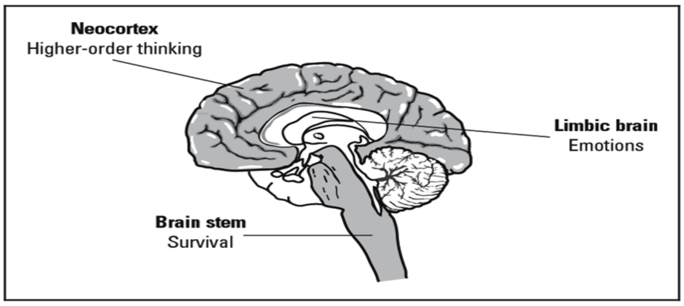
Amos Tversky was little patient with these efforts; he called on theorists who tried to rationalize the violations of the utility theory ‘lawyers of confusion’, since together with Kahneman they went in a different direction. They maintained the theory of utility as a logic of rational choice, but abandoned the idea that humans are perfectly rational in their choices. They set out to develop a psychological theory that would describe the choices people make regardless of whether they are rational or not. In the perspective theory (prospects), the decision values are not identical to the values of the probabilities. (Satpathy, et. al.; 2014).

In an attempt to answer these questions, Samuel Mclure, David Laibson, George Loewenstein and Jonathan Cohen[xiv], using functional magnetic resonance imaging (fmri), examined the neural correlate of time discount while subjects made choices between monetary reward options that varied across time. The experiment consisted of giving the participants a choice between a sum in the short term and another in the long term, the first being less than the second. Both options were separated by a minimum time lag of two weeks, and in some pairs of options, the earliest option was immediately available. The hypothesis was that the behavior pattern of the two parameters (β and δ) arises from the joint influence of different neural processes. The β related to the limbic system and the δ related to the lateral prefrontal cortex and other structures associated with higher cognitive functions (the more rational ones).

However, there is much that is known about the neural processes underlying the emotional / affective responses to risks. Most of the risk-averse comportments are caused by fear responses / fear of risks, where this fear seems to originate in the region called the amygdala (the center of fear, located in the emotional part of our brain). The amygdala constantly monitors new stimuli that indicate potential threat and responds to inputs from both automatic and controlled processes in our brain. However, the amygdala also receives stimuli from the cerebral cortex (the most rational part of the brain), which can moderate or even eliminate the emotional response. What results did the researchers obtain? Basically, there would be two systems involved in such intertemporal decisions:

- Parts of the limbic system (emotional zone of the brain) associated with the dopamine system of the central brain, including the paralimbic cortex, which would be triggered by decisions involving immediately available rewards;
- Regions of the lateral prefrontal cortex and the posterior parietal cortex (eminently rational areas of the brain), uniformly involved in intertemporal decisions independently of the delay in time.



This neuroeconomic finding is consistent with the evidence that consumers act impatient today but prefer to act patients in the future, also supporting the hypothesis that different neuronal systems are activated by intertemporal decisions: the impatience of the short term, which is driven by the limbic system (emotional, not deliberative), and that responds preferably to immediate rewards and to a lesser extent to future rewards; and long-term patience, dominated by the lateral prefrontal cortex and associated structures (the most deliberative parts of our brain), which can rationally evaluate exchanges between abstract rewards, including rewards over longer periods.

Conclusion

Undoubtedly this neoclassical model, which is simple and unreal, has been enormously useful for doing science, as we will see in the next chapter, where we analyze whether neuroeconomics could imply a paradigm shift or not. However, through this model of Glimcher, we have been able to appreciate that today we can measure (via neuroimaging) the true utility that each person obtains from each good or service, the so-called sv (subjective value), which would be observed in our brains depending on the degree of "neuronal firing rate", which is generated when we perceive and evaluate said good or service to acquire it or not; and also that said utility or vs would be cardinal, not ordinal, and that it "learns", that is, it would improve day by day thanks to our "neuronal plasticity". That is, before this new empirical evidence, will continue maintaining the old neoclassical models?

It is believed that future research should better assess what kind of discount functions are ideal for predicting real-world economic decisions, and generally improve methods for measuring intertemporal decisions, where Neuroeconomics will undoubtedly play an important role.

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