Neuroeconomics, decision-making and rationality

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1. Introduction

“Economics is a science which studies human behavior as a relationship between ends and scarce means which have alternative uses”. Whereas the scientific evolution of economics could have hastened the discipline’s obsolescence, it would appear that Lionel Robbins’s famous definition (which dates back to 1945) is just as relevant today. While the “optimal allocation of scarce resources” has long been highlighted in neoclassical economics, it seems to have been somewhat overshadowed by the rise of behavioral economics and neuroeconomics. At present, the question of human behavior – the other element in the abovementioned definition – is at the heart of economic research. The aim is more to know the “how” and “why” of human behavior, rather than to predict optimal behavior. Undeniably, while the ultimate end remains focused on human wellbeing, the scientific aim of economics has shifted, notably as the principle of standard rationality has been called into question. Indeed, according to the hypothesis of substantive rationality, human behavior always tends towards set goals, and economics alone is sufficient to understand human behavior, which is entirely predictable. However, once we acknowledge the fact that human decisions are not perfect, resorting to psychology and experimental analysis is inevitable should we wish to understand the actual logic behind economic behavior. Owing to these two influences, the evolution of the field of economics has recently been characterized by the breakdown of standard models of decision-making, faced with the requirement of better descriptive power and due to the emergence of new, more robust models for behavioral observation. Inasmuch as the renewal of economic models was triggered by challenges to standard rationality, we found it opportune to examine the possible contributions of the neurosciences and neuroeconomics to the debate on rationality.

With regard to behavior, experimental economics and psychology, combined with calling into question standard economic rationality, have uprooted prior certainties. Neuroeconomics has arrived at the right time to cast light on this debate by favoring a

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particular kind of rationality. This has already confirmed the fundamental role that emotions play in decision-making, and could also confirm or contradict a certain number of results and conjectures of psychologists. Our approach will favor a hedonic approach, partly following on from Bentham's utilitarian approach (1789), which states that utility is derived from pleasure and pain and is the major determinant in choices and actions. As highlighted by Kahneman, Wakker and Sarin (1997), the field of economics set aside Bentham's utility, as it could not be measured, and gave priority instead to revealed preferences. In their 1997 publication, these authors asserted that four types of utility can be distinguished following a reward: predicted utility, decision utility, experienced utility and remembered utility. Thus, the representation of the satisfaction linked to a reward at a given moment combines several types of utility, combining anticipation of a reward, its hedonic impact, or the memory of similar rewards. For Berridge and Aldridge (2008), the observable activation of areas of the brain presents a potential empirical counterpart to these various types of utility. More specifically, we emphasized emotions as a component in the decision-making process (negatively or positively), particularly emotions related to the reward circuit. This pattern is replicated in the four dimensions of an economic agent's choice: present choice, choice under uncertainty, over time or in a context of social interaction. For each type, going beyond the original model results in complexity that can possibly be clarified thanks to neuroeconomics.

The first hypothesis, which held sway for a long period of time, is that of a rational economic agent that chooses any favorable option at any point in time. The explanatory power of this approach was seriously jeopardized due to the limited cognitive capacity of economic agents and the imperfection of information. Herbert Simon's more reasonable hypothesis of limited rationality underscores the pertinence of understanding how an individual acts in a situation of imperfect information that gives learning and social factors their full place, while taking into account the individual's cognitive constraints. With regard to the role played by emotions, neuroeconomics shows that many decisions prove correlated to the neural activity of emotional circuits. Thus, purchasing decisions represent an important field for neuroeconomics enquiry. For Erk *et al.* (2002), consumption of products associated with wealth or social status produces pleasure that can be identified in the activation of the reward circuit. In the same vein, Deppe *et al.* (2005) show that the presence of a brand appreciated by an individual activates his brain's emotional areas. As such, emotions appear to act as a crucial link in brand preference. In another perspective, Weber *et al.* (2007)

focus on studying the endowment effect³ within an experimental framework, and observe a negative emotional response (visible via activation of the amygdala) in the specific case of selling something one owns rather than buying.

With regard to decisions in situations of uncertainty, the expected utility model (or EU) was an absolute reference for a long period of time. However, this model was initially challenged following experiments conducted by Allais and Ellsberg, and further contradictory evidence came to light thanks to the development of experimental economics and the contribution of psychologists. On the one hand, experiments deepened knowledge of choice behavior in situations of risk (non-linear deformation of objective probabilities, aversion to risk in a context of gains, appetite for risk in a context of losses, etc.) and enabled the same behavior to be apprehended in ambiguous situations⁴. On the other hand, research by Kahneman and Tversky (1979) raised numerous objections to the EU model by highlighting notably that choices are often dependent on a framing effect and apparently frequently guided by heuristics (Tversky and Kahneman, 1974). Neuroscientific results confirm known empirical results in decisions in a risk context (aversion to risk in a context of gains, appetite for risk in a context of losses and a general aversion to ambiguity— Smith *et al.* 2002), by highlighting the crucial role of emotions. Thus, Tom *et al.* (2007) focus on the neural determinants of aversion to losses, and show the predominant role played by the ventral striatum ventral and ventromedial prefrontal cortex (VMPFC), two areas of the dopaminergic circuit associated with expecting and obtaining monetary rewards (Knutson *et al.* 2001). Backing these findings, observation of the brain function of subjects making financial decisions highlights the role of “anticipatory affects” during investment choices (Kuhnen *et al.* 2005). According to these authors, anticipatory neural activity can predict financial choices and their pertinence or irrationality. Thus, activation of the nucleus accumbens, which plays a central role in the reward circuit, is shown to be linked to anticipation of risky decisions or risk-taking, whereas activation of the anterior insula (negative emotion) foreshadows risk-adverse choices, or even cautious stances. This contribution not only highlights the influence of fortuitous emotions, but also supports the hypothesis of anticipatory affects that modify the perception of rewards and risk aversion⁵.

³ The endowment effect (Thaler 1980) corresponds to an individual's tendency to value an object more when he owns it than when he does not own it.

⁴ Ambiguous probabilities describe events whose probability is not known precisely.

⁵ In a way, this notion of anticipatory affect echoes back to the somatic market hypothesis (Damasio 1994 and Bechara *et al.* 1997), whereby healthy

In another field, the discounted utility (or DU) model, formulated by Samuelson (1937), was long considered the reference for intertemporal choice. One of the major stumbling blocks in this model is the hypothesis of a constant discount rate that underlies the temporal coherence principle (Strotz 1956). According to this principle, an economic agent's discount rate is not affected by a shift in the timeframe. For instance, if a subject prefers €90 today rather than €100 in a week's time, temporal coherence would require that he also prefers €90 a year from now rather than €100 in one year and one week. However, empirical and experimental observations (Frederick *et al.* 2002) have shown that individuals weight a given timeframe more if it is close than if it is far off. In other words, the discount rate is degressive over time, and the hyperbolic time discounting hypothesis (Ainslie 1975) is realistic. Furthermore, we note that gains are discounted at a sharper rate than losses (this is known as the "sign effect"; Thaler 1981, Loewenstein 1987)⁶. Neuroeconomic experiments show that the frontoparietal areas – the location of higher cognitive functions – are generally activated for all intertemporal choices but show no particular sensitivity to whether a reward is imminent. Conversely, the limbic system (which is crucial in emotional processes) plays a role in the apprehension of immediate rewards (McClure *et al.* 2004a and 2007). According to this view, the preference for the present is a meaningful phenomenon and is moderated by higher cognitive functions. Xu *et al.* (2009) show that the discounting of losses, whether carried out today or at a later date, always involves cerebral areas associated with negative emotions (the insula, thalamus and dorsal striatum), even though immediate losses stimulate these emotional zones more intensely.

In contexts of social interaction, games such as the ultimatum game, the dictator game, the trust game and the public goods game have shown that choices cannot be attributed to self-interest alone. Resolving this quandary required a social preference hypothesis, characterized by the fact that an individual takes into account – positively or negatively – the material situation or wellbeing of others. This results in various competing models of social preference, whereby individual satisfaction links an individual's gains with those of others, based on arguments of reciprocity or aversion to inequity (see Fehr and Schmidt [2003] for an assessment of the various contributions to this question). The role played by emotions is also confirmed in the framework of social interactions.

individuals (i.e. not suffering from VMPFC lesions) generate somatic markers that enable them to make efficient decisions even before being fully aware of the stakes of a problem.

⁶ Thus, a high proportion of subjects prefer to suffer a risk now rather than putting it off in time (Redelmeier and Heller 1993, *inter alia*).

Corcos and Rizopoulos (2011) emphasize the fundamental role of reward and punishment circuits in prosocial behaviors. When individuals choose to give to a charitable institution (Moll *et al.* 2006) or to help finance a public good (Harbaugh *et al.* 2007), the reward circuit is activated. Likewise, behaving loyally and responding to signs of trust (King-Casas *et al.* 2005), or acting fairly (Tabibnia *et al.* 2008), are all egocentric decisions insofar as they trigger hedonic emotions. On the contrary, being treated unfairly or inequitably activates the punishment circuit (insula), and we can predict that the individual will reject a proposal he deems unfair (Sanfey *et al.* 2003). These factors are present in situations in which individuals are betrayed. The resulting pain motivates a “desire” to punish that in turn generates a positive emotion when punishment is inflicted (De Quervain *et al.* 2004).

Regardless of the decision-making contexts addressed, the hedonic dimension of positive or negative emotions appears to contribute to the decision, and these observations match those of psychologists in more than one way. Neuroeconomics, via the technology it uses, is well positioned to assess this opportunity for convergence of economics and psychology. Neuroeconomics does not just identify the presence of emotions, but also aims to determine their role in the decision-making process. From this standpoint, certain observations suggest that emotions result from an initial neural circuit that may be moderated, depending on the situation, by a second circuit that involves higher cognitive functions. This article is thus an attempt to understand and analyze the contribution of neurosciences to the debate on rationality of economic choices, by focusing on reward and punishment. As a first step, we will address the problem of the hedonic decision-making process, notably the neural trade-offs that may occur at the time a choice is made (section 2). In section 3, we will analyze substantive rationality by showing that neurosciences enable internal and external rationality to be distinguished. These observations will naturally lead us to look at the question of rule-rationality (section 4), by endeavoring to understand what the advances of neurosciences enable us to say on this topic.

2. Neural trade-offs

While emotions bear particular importance, notably through the interaction of the reward/punishment circuits, decision-making remains strongly influenced by the conflict between emotion and reason. Thus, intertemporal choices are a trade-off between the pleasure of immediate consumption and the more “reasonable” choice of greater consumption at a later date, whereas prosocial behavior results from a trade-off between “the warm glow of giving” and the cost or monetary loss of the gift. While this notion of a trade-

off is pertinent, it is certainly not limited to simply counting positive and negative emotions. Neural trade-offs take many forms and activate competing or complementary neural systems. They can occur consciously or unconsciously.

Neurosciences appear to reveal the coexistence of several decision-making systems (Sanfey *et al.* 2006, Sanfey and Chang 2008). The first system appears to handle routine, automatic decisions and integrates the emotional dimension. A second system, based more on deliberation, gives a greater place to the usual processes of rationality in choosing (making trade-offs, behavior guided by anticipation of a reward, exploring/exploiting various possible outcomes, etc.). This dichotomy in decision-making processes notably suggests the approach of Kahneman and Frederick (2002), who distinguish between a system 1 involved in automatic and emotional decisions, and a more deliberative system 2. While these two systems interact with each other and share the same neural substrates, studies tend to prove that they are nevertheless parts of very different parts of the brain. Thus, the automatic mode relies more specifically on the posterior cortical structure and subcortical systems. The handling of emotions involves the limbic system, which comprises in particular the reward circuit (notably the ventral tegmental area and the cortex areas it projects to: the nucleus accumbens, anterior cingulate cortex, and the ventromedial prefrontal and orbitofrontal cortexes), as well as other areas such as the amygdala and the insular cortex (Sanfey *et al.* 2006). Conversely, the deliberative process (planning, problem-solving) activates the anterior and dorsolateral regions of the prefrontal cortex, along with those of the posterior parietal cortex.

It is therefore reasonable to enquire how these two systems interact. It appears that both systems are competing and cooperative at the same time. Numerous research articles (Sanfey *et al.* 2006, de Quervain *et al.* 2004, King-Casas *et al.* 2005) study the trade-off that occurs between the reward/punishment circuits and the deliberative circuit. These articles notably highlight the causal link between choice and the *relative* level of activity of the two zones.

With regard to social interaction, the findings cerebral imagery studies (Sanfey *et al.* 2003) enable us to predict that in an ultimatum game, a subject that has received a proposal he considers unfair (strong activation of the insula) will probably reject it. Yet Van't Xout *et al.* (2005) go even further, underscoring the trade-off between hedonic experience and the deliberative process. They show that the relative intensity of activity in the zones of the reward/punishment and deliberation circuits (notably the dorsolateral prefrontal cortex, or DLPFC) is the crucial determinant in decision-making. Individuals appear to effect a trade-off between their reflexive rejection of a proposal taken as an insult, and

accepting the proposal (a more “reasonable” attitude given the subsequent monetary gain). By disrupting the function of the prefrontal cortex, these experiments show that the probability of rejection increases, as if the “monetary gain” dimension no longer carried enough weight.

In purchasing decisions, several experiments involving similar products but different brands (McClure *et al.* 2004b, Deppe *et al.* 2005), lead us to believe that both neural systems cooperate to produce subjects’ preferences. When judgments on two similar products (e.g. Coke and Pepsi) are based solely on sensorial information, the level of activation of the VMPFC, linked to reward, predicts subjects’ choices (McClure *et al.* 2004b). However, information on the brand reshapes these choices. Hence Deppe *et al.* (2005) observe a burst of activity in the cerebral zones linked to emotions, combined with a reduction in the activity of the zones involved in memory and reasoning, after subjects are informed of the brands.

Brain activity imagery also assesses behavioral deviation compared to the archetypical consumer choosing only according to the criteria of preference and price. Recent neuroscientific advances back the idea that purchasing decisions involve a trade-off between the “pleasure” of buying and the “pain” of paying. Knutson *et al.* (2007) show that choices are correlated to the activation of areas associated with anticipated gains (the nucleus accumbens, a component of the reward circuit), whereas the impact of prices results in activation of the insula (often associated with negative emotions) in cases of high prices, and in activation of the medial prefrontal cortex (or MPFC, an area activated in calculation and assessment of consequences) in cases of low prices. Models of the purchasing decision show that these brain areas are able to explain the resulting choice (i.e. whether to buy or not). From an economic standpoint, this resembles a trade-off between the interest in the good (observed via activation of the nucleus accumbens) and its price (observed via the insula if the price is high or via the MPFC if it is low). Excluding any economic bias, it would appear, at the very least, that several neural circuits are effectively activated and the instantaneous preference is modulated by deliberative functions that take into account the price to be paid.

In terms of intertemporal choices, the findings of neurosciences (McClure *et al.* 2004a) suggest the coexistence of several neural systems, which are activated differently when trade-offs are made between immediate and deferred rewards. Each of these systems favors a specific decision: on the one hand, the limbic system, focused on immediate rewards; on the other, the lateral prefrontal cortex and posterior parietal cortex, both of which are generally focused on intertemporal trade-offs. The authors of this

study show that the relative level of activation of these brain areas points to the choice the subject will make. Thus, stronger activity in the prefrontal and parietal cortexes indicates that subjects will choose long-term options. These observations suggest that the prefrontal and parietal cortexes may be able to exercise cognitive control over the reward circuit, which, in some cases, would enable consumption to be postponed by overcoming the temptation for immediate pleasure.

The findings of neurosciences could thus validate a standard approach to hedonic decision-making based on a deliberative process that integrates the weight of emotions (understood as pleasure and pain)⁷. This would echo Bentham's aforementioned utilitarian approach, for which emotions are assimilated to utility weights. In a large number of situations (social or intertemporal choices or purchase decisions), it would appear that behavior can be determined by the level of activation of the reward circuit which could thus be one of the main foundations of decision-making. Such an approach allows for an "explanatory" model of decision-making that is no longer simply predictive, by placing pleasure and pain at the heart of decision-making, whether these sensations are deliberately sought after or simply experienced (without control or anticipation). It is thus reasonable to wonder whether incorporating hedonic emotions into the decision-making process in general and into the deliberative process in particular is a sufficient condition to prove the rationality of decisions.

3. Substantive irrationality

While we now know the positive role played by emotions in decision-making (Damasio 1994), the fact that decisions may be subject to deliberative control is no proof of their rationality. Thus, studies on brain damage, particularly in areas related to emotions, has yielded contradictory findings in terms of act rationality. Observation of subjects suffering from brain damage shows that the absence of emotion increases external rationality in some choice contexts, while reducing it in others.

A study by Shiv *et al.* (2005) is one example, showing that emotions can even play a negative role in investment choices. In this experiment, healthy subjects in an investment game with favorable actuarial conditions make less advantageous investments than subjects suffering from neural damage to emotional zones of the brain. The latter invest coherently throughout the game's iterations, whereas the normal and control subjects (the latter are patients having suffered damage to brain areas not linked to emotion) make

⁷ Via the reward/punishment circuits.

investment decisions that are increasingly poor. Likewise, Hsu *et al.* (2005) show that subjects suffering from orbitofrontal lesions are impervious to the risk/ambiguity distinction. In other words, the subjects adhere more to the expected utility criterion than do healthy subjects! In the same vein, the recent contribution by De Martino *et al.* (2010) shows that an amygdala lesion considerably reduces loss aversion, which can lead to unhampered risk-taking. Another study conducted by Krajcich *et al.* (2009) concluded that damage to the prefrontal cortex goes hand in hand with the extinction of feelings of guilt. Here again, the behavior of subjects with brain lesions may appear closer to the predictions of standard economic theory. We would also cite the contribution of Koenig and Tranel (2008), who show that individuals with damage to the ventromedial prefrontal cortex do not suffer from the Pepsi paradox⁸.

The study of patients with brain damage is thus a source of data showing that choice behavior is not characterized by an *external* rationality. These few illustrations argue in favor of a distinction between internal and external rationality – a distinction that takes full shape due to the major role played by emotions in the decision-making process in the brain. Substantial rationality of an individual's actions can be viewed in an internal or external perspective. Internal rationality corresponds to the internal coherence between an individual and his actions. In this case, the individual will make a decision that matches his internal equilibrium; this is a position of consonance (Festinger 1957), as the choices result from a trade-off between cognitive and emotional arguments. Conversely, external rationality is similar to the outcome of substantive rationality inasmuch as an act's pertinence and efficiency will be judged according to the situation. This dichotomy enables us to apprehend the situations in which deliberative processes integrating emotions may present internal rationality without necessarily being optimal from an external standpoint, i.e. considering the situation.

In this respect, the framing effect is a strong example of *internal rationality leading to external irrationality*. Initially identified by Tversky and Kahneman (1981), this effect shows that human decisions are substantially influenced by the way that a problem is presented. In their brain imagery study (fMRI), De Martino *et al.* (2006) present one choice in two different ways. After receiving £50, the subject may play the lottery or keep £20 (a gain frame). In the second frame, the subject may either play the lottery or lose £30 (a loss frame). Whereas subjects should make the same decision in both contexts (according to external rationality), in fact, in the gain

⁸ Namely, a preference for Pepsi in blind taste tests, but a preference for Coke when the brand is known.

frame, subjects opt not to play the lottery, whereas in the loss frame, they prefer to play. As subjects carried out these tasks, researchers observed increase activity in the amygdala (notably linked to emotions of fear) when the subject's decision was in the direction favored by the framing effect⁹. From the standpoint of prospect theory (Kahneman and Tversky 1979), activation of the amygdala is consistent with the observation that individuals generally exhibit risk aversion in a situation of gains and an appetite for risk in a situation of losses. In both cases, activation of the amygdala underscores a feeling of fear or aversion to losses that depends on the way of considering the problem. In terms of internal rationality, the framing effect appears to be a reflection of the aversion to losses; when the individual thinks he can gain £20, he is afraid of losing more and avoids playing the lottery; when he thinks he may lose £30, his aversion to losses prompts him to opt for the lottery. This interpretation appears to be confirmed by the recent contribution of De Martino *et al.* (2010), which indicates that the amygdala mediates loss aversion.

Along the same lines, the framing effect highlighted by Knutson *et al.* (2008) provides a good illustration of the potential gap between internal and external rationality. In this article, individuals shown erotic images are then inclined to make riskier investment choices. In this example, images activate the nucleus accumbens and place the individuals in a situation of reward expectation and appetite for risk. The resulting risk-taking thus shows substantial internal coherence, even if, from an external rationality standpoint, the two events (the images and investments) are independent and the images should not have had any impact on the investors' behavior.

This same opposition between internal and external rationality is visible in the choice between Pepsi and Coca-Cola (McClure *et al.* 2004b). In a blind taste test, subjects appear to prefer Pepsi. However, when they are aware of the brand, their preferences are reversed. The internal mechanism that consists of giving a strong weighting to the brand (activation of the DLPFC and the hippocampus) leads to a choice that, from an external rationality standpoint, is not coherent: subjects do not choose the beverage that they consider to have the best taste.

Thus, while the distinction between internal and external rationality is imposed by the emotional nature of the stimuli at work, it does not suffice to highlight the rationality of behavior. The external act rationality and the congruence between internal and external are not verified at all time, and moreover, human behavior does not appear to result more from internal rationality. What status

⁹ Choosing to keep the £20 in the gain frame and choosing to play the lottery in the loss frame.

should be attributed to dissonant behavior¹⁰ that contradicts or comes up against subjects' beliefs? This type of behavior will lead to situations in which there is a violation at least of internal rationality, if not of external rationality. Hence demonstrating that the economic agent applies internal rationality that is the fruit of his learning and experience offers little prospects in terms of predictive power. We can therefore reasonably believe that exploring internal rationality will hardly reveal indications in terms of understanding behavior, and the neural trade-offs that appear to be at work do not renew the credibility of the hypothesis of substantive rationality. This suggests that human decision-making, in its hedonic perspective, as a product of pleasure, pain and more or less conscious cognitive controls, cannot claim a status of act rationality.

Rather than focusing on internal, self-centered rationality, determined by neurobiological factors, it would appear useful to apprehend the final goals of internal coherence. Thus, behavior could be based on rule rationality rather than implementing act rationality. Somehow, the individual could choose between resorting to heuristics and revising acquired behavior according to the situation and the subject's past experience. Inquiring into rule rationality would thus consist of considering whether the decision-making process is, on average, the best and most suitable given the situation.

4. Discussion

The concept of rationality could thus be understood from the standpoint of making a *decision*, in the strict sense, or from the standpoint of a meta-rationality of the decision that questions the *process* of choosing. This distinction obviously echoes that of Herbert Simon (1947, 1976) between substantive and procedural rationality. Substantive rationality entails the suitability of behavior in view of fixed goals, given the contextual constraints, and thereby enables the coherence of decision-making to be assessed. Conversely, procedural rationality, by integrating the imperfection of human decisions, emphasizes the rationality of decision-making processes. This idea was asserted as early as 1947 by Simon, with his concept of "satisficing" to characterize decision-making methods that lead to satisfactory, albeit not optimal, solutions. Extending this distinction, with a view to considering the contribution of neuroscientific observations on the question of the rationality of decisions and of decision-making processes, we will rely on the dichotomy laid out by

¹⁰ This is the case when an individual is forced to defend opinions that he disagrees with.

Aumann (2008)¹¹ between act rationality and rule rationality. Act rationality refers to the maximizing principle of standard theory, according to which individuals will, after deliberation, adopt behavior suited to bringing them the highest level of satisfaction. Conversely, rule rationality is based on the principle that individuals adopt a decision-making process that “generally” yields the best response to the situation at hand. Behavior therefore results from the behavioral rule adopted. “Optimization” would involve the rule, not the behavior itself, and does not presuppose a conscious deliberative mode.

In this perspective, the two decision-making processes (i.e. emotional/routine and deliberative) could be considered to complete each other, with blurred borders and a complementary fit aimed at generating the best behavioral rule. This is the case of the learning process. So long as an individual is learning about the contingency between action and reward, the reward circuit encodes the divergence between the anticipated and actual reward. The individual, in accordance with his deliberative process, adjusts his choices so that the two coincide. Once the link is established, routine and automatic processes take the lead. If the reward ceases after the learning phase, the acquired behavior would not necessarily cease or would stop only after a certain length of time (Dickinson 1994, Dayan and Balleine 2002).

This behavior, which sometimes activates the automatic process and sometimes the deliberative one, would result from rule rationality: according to the circumstances, the most suitable system would come into play. This is illustrated by the abovementioned framing effect study by De Martino *et al.* (2006). As we have seen, cerebral imagery has revealed the predominant role of the amygdala in explaining the behavioral bias. Conversely, for choices that go against this bias (i.e. when individuals are not influenced by the experimental framing), increased activity is observed in the anterior cingulate cortex and the dorsolateral prefrontal cortex¹². This observation appears to lend credence to the idea of a conflict between two neural systems, the first of which is more emotional in nature (based on the amygdala), whereas the second is more analytical (and notably signaled by activation of the cingulate anterior cortex). Thus, two neural systems could determine the decision, with the first (more emotional in nature) being modulated or even overridden, depending on the circumstances, by the second (more “deliberative” in nature).

¹¹ His predecessors include Bentham (1789), with “act utilitarianism”, and Harsanyi (1980), who spoke of “rule utilitarianism”, although these two concepts are more normative than rationality.

¹² The anterior cingulate cortex is involved in managing conflicts and detecting errors; the dorsolateral prefrontal cortex is activated along with higher cognitive functions.

However, Aumann's bees parable (2008) contrasts this idea of the appropriate process being activated at all times. In this parable, after a "learning window" during which bees identify the flowers that produce the nectar they need, they gather pollen without reassessing their choices. If the flower ceased to produce nectar for whatever reason, their routine behavior could cause them to starve. This parable does indeed raise the problem of heuristic rationalities such as conservatism. It casts light on how the learning process should be understood. While resorting to automatic responses can be efficient (as it is economical), the question of its rationality, at all times, is unproven. In general, repeated tasks or routine actions lead to a sufficient level of satisfaction (Simon 1962). However, to apply Aumann's argument, the rationality of heuristics must probably be considered from an evolutionary standpoint.

The article by Weber *et al.* (2009), studied and contextualized by Bourgeois-Gironde and Guille (2011), focuses on the paradox of monetary illusion and illustrates this point of view. Two groups of subjects are confronted with gains that are identical in purchasing power terms, but with different nominal values. In this context, the authors show that the ventromedial prefrontal cortex, linked to the reward circuit and the evaluation of goods, is activated more when individuals perceive high amounts (in nominal value terms). As a result, it appears that what is valued is derived more from the nominal value than the purchasing power equivalent. Once again, we can assume that this characteristic is part of an evolutionary perspective in which those individuals with the "most" in terms of physical quantity proved to be the strongest and the most able to resist enemies, and were therefore selected. It is as if individuals attributed the same status to nominal amounts as to physical quantities. Moreover, this illusion is made possible and perpetuated by the fact that money is a means to acquire these physical quantities. Thus the monetary illusion appears to result from a generally optimal process on an evolutionary level that tends to value a form of physical property, and by extension, money.

The discussion highlighted the idea that the brain is characterized by a rule rationality that enables the survival of the species, which is attributable to its ability to implement rules that optimize action in repetitive reference situations that require resorting to immediate actions. Heuristics, revealed by Tversky and Kahneman (1974), result typically from this system, as they enable rapid decision-making, while resulting from a limited form of rationality, as they lead to sociocognitive errors and framing biases. At the same time, human intelligence is characterized by learning and cognitive control that frees it, depending on the contexts encountered, from the cognitive biases of routine systems. This

thesis of a dual system appears to be relatively well supported by neuroscientific observations. It is well suited to the idea of the brain's plasticity, as shown by neurosciences. This architecture of the decision-making process presents the considerable advantage of echoing the fairly consensual debate among psychologists regarding the existence of two decision-making systems (see Evans [2008] for a summary). This architecture also offers a common framework for the dichotomy at work between standard economics and behavioral economics.

However, rather than a formal dichotomy between these two systems, it would appear that there is a continuum of systems that lies between these two extreme endpoints. Furthermore, all these facts appear to be able to fit with different types of architecture for the decision-making process. Neuroscientific observations also appear to converge towards an alternative model of choice that is distinguishable based on the underlying decision-making process. This model is based on the idea of a two-stage decision-making model that involves an evaluation stage followed by a choosing stage (Glimcher *et al.* 2009). The evaluation stage is aimed at representing the values of actions and goods. It is structured by the learning mechanisms in the brain that yield, at a given point in time, the subjective value of an option. The first learning mechanism was identified in the 1990s by Schultz, who demonstrated that the dopaminergic neurons of the striatum and the frontal cortex are able to encode the reward-prediction error. These advances suggest that the brain is able to evaluate. Hence a necessary choosing stage, which takes the evaluations of various options as input, enables the physical action of the decision-maker to be guided.

Going even further, Brocas and Carillo (2008a, 2008b) believe that the cumulative results in terms of brain functions can be used to build theoretical models that are both prescriptive and descriptive, as they are based on the observation of the very genesis of behavior. In their 2008 contribution (2008b), applying the tools of the principal/agent theory, they considered the brain's function as a hierarchical organization for which controlled processes constrain emotional processes that present limited rationality due to their underlying imperfect information. Using as inspiration neurosciences and the idea that several systems are at play simultaneously within the brain, they assert that by modeling the explicit interactions between these various systems, it is possible to substitute microeconomic foundations for the traditional hypotheses regarding preferences (Brocas and Carillo 2008a). While it is too early to judge whether this approach will stand the test of time, it apparently offers proof of the synergies at work and is a possible way towards achieving a synthesis between economics and neurosciences.

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