How regret moves individual and collective choices towards rationality

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1 IDENTIFYING REGRET

At first sight, regret, which is semantically very ambiguous and confined to psychological notions such as disappointment, remorse, or even repentance, is not the 'smartest' state of mind we can entertain in the course of our life. It is the feeling that we have been less than optimal in particular situations or longer stretches of time, where we could have acted on better lines, and we know it or realize it now, while in the throes of that negative emotion. It is ironical that the author most associated with a vindication of the virtuous role of emotions in decision-making in contemporary popular neurobiology, namely, Spinoza as interpreted by Damasio (Damasio 2004), emphasizes the irrationality of regret: 'Repentance is not a virtue, that is, it does not arise from reason; instead, he who repents what he has done is twice wretched, that is, lacking in power' (Spinoza 1677 [1996], p. 4). The individual not only has been practically suboptimal but a negative feeling accrues and prolongs her helplessness. Regret, thus viewed, does not represent the emotional side of a retrospective and corrective, cognitively driven process. To refute that view and make apparent how regret can help optimize decision-making processes rather than reinforce past failures, we need, first, to decompose between backward-looking and forward-looking aspects of regret and, second, to better understand the articulation between its emotional and cognitive components. Taken altogether, these distinctions will permit us to define regret as a biologically anchored learning mechanism liable to direct decisions along an optimal path. In the absence of this psychological device, which apparently consists of dumbly lamenting over spilled milk, our decisions would really be dumber, as it is likely that we would not become aware, or at least sensitive, to our past mistakes. As for the emotional part, we are, by means of emotions such as regret, sensitized to suboptimality. However, the forward-looking and cognitive component is what makes regret a smart mechanism, and ourselves smarter by the same token, to the extent that the aversive aspect of felt pangs of regret drives up regret-avoidance behavior over the repetition of similar decision situations and, through the conscious anticipation of the emotional impact of comparatively bad or good consequences of a choice over several available options, it generalizes to a whole range of repeated or even one-off decisions. This pervasiveness of regret and its inherent cognitive nature triggered attempts at incorporating it in formal decision-theoretical frameworks.

Regret, with its conceptual correlate disappointment, is one of the rare emotions which have been singularly identified and incorporated in formal decision-theory. Elster (1998) extends a long argument about how economists fail to account for specific emotional mechanisms. Most of the discussion about the relationship between emotions and rationality has been couched in general terms, falling short of phenomenological

characterization and a specific analysis of emotional mechanisms potentially associated with behavioral optimization in choice contexts. This amounts to deliberate ignoring or downplaying of game-theoretical models of guilt or envy and regret-based decision-theory that were already developed in the 1980s and 1990s. However, this also triggers attention and effort towards the possibility to more finely integrate the psychological description of emotional mechanisms – including phenomenological, behavioral and neurobiological levels – and decision-theoretical normative issues. At the same time, this reveals the tension between descriptive and normative relative imports in accounting for human rationality. One obvious way to alleviate this tension is to uncover some normative aspects of emotions.

What has distinguished regret among other emotions is that it definitely bears a cognitive component. It is an articulate, sensitive state of mind. Regret consists in feeling negatively the comparison between two states of affairs. This involves a series of sub-performances, alternatively pointing to cognitive processes and hedonic states and, on the whole, their integration into a unified affective state. Imagine you have forgone an optimal option and now find yourself in a position to compare what you have got with what you could have got; this implies your ability to:

- engage in counterfactual thinking;
- ascribe a value to a present state of affairs and to a counterfactual one; and
- compare actual and counterfactual values.

This becomes even more intricate when we envision anticipated regret. Anticipated regret is the heuristic we need to incorporate into smart regret-based behavioral decision-theoretical models, as, on its basis, individuals will tend to avoid negative future consequences. From a cognitive standpoint, the smartness then required amounts to the following:

- representation of possible future states of affairs;
- hedonic simulation of the future (also known as mental time travel);
- ascription of value to future alternative states under different courses of actions taken; and
- comparison of utilities derived from possible alternative states.

The integration of these cognitive sub-processes functionally yields a future utility-weight in present decisions. Specific cerebral mechanisms underpinning each of these processes and their functional integration have been described (Gilbert and Wilson 2007; Boyer 2008; Schacter et al. 2008). It is worth noting from the outset that the way regret has entered decision-theory in the past three decades, as a rival to a standard model of expected utility theory, relies on a much more stylized version than that which cognitive and affective neuroscientists probe into our brains. However, we think there is enough overlap between the working definitions of regret respectively adopted in psychology and in economics (especially in experimental decision-theory) to allow a fruitful hybridization of the approaches and uncover regret as a smart mechanism both from a psychologically realistic and a formally tenable perspective. The main distinctions to be drawn in both contexts are in terms of available information, responsibility, and valence (in that order),

Table 11.1 Varieties of decision-theoretical emotions

	+	–
Information	Regret	Disappointment
Responsibility	Regret or remorse	Deploring
Valence	Rejoicing	Regret

rather than in terms of mental abilities to project ourselves into alternatives and experience feelings about them (Zeelenberg 1999).

Under that most basic view, to experience regret, individual X needs to know that her action A has led to consequence C and to further know that, had she taken another action, A', the consequence would have been C'. Now, the difference, in terms of utility, u(C) – u(C'), if negative, is what regret amounts to.

If we weaken or modify an element of this sequence, a typology of alternative 'decision-theoretical emotions' derived from this definition of regret is generated (see Table 11.1).

More forms of regret and related emotions can be encompassed if we consider the timing of the emotions with respect to the unfolding of the action; in particular regret can be *post hoc*, *ex ante* or online (we sometimes regret what we are doing while doing it). What has interested decision-theorists is the learning process associated with regret which ensures the transition from *post hoc* regret to anticipated regret and bias decisions to a predicted error minimization procedure (also known as minimax-regret). Young (2004) excellently accounts for this transition from experienced regret to anticipated regret. That transition goes from a backward-looking emotional state to a cognitive anticipation of future consequences and is at the core of what makes regret a potential smart mechanism in decision-making. In a past-payoff decision-model based on the elimination of regret, a single agent who faces a t-times repeated decision problem will try to eliminate or minimize regret over the period $[1 - t]$. The agent makes her choice over a set of actions A and obtains a payoff following each action taken. We do not have to consider the time that elapses between the action and its feedback, even though of course in a richer regret-based model this parameter is likely to play a role. The feedback of the action is not in itself the parameter to elicit regret: it has to be contrasted with the expected outcome or, differently, with the information about what she could have obtained had she had taken another course of action, say a. Let us suppose that second comparison is made possible at the end of period $[1 - t]$. As of period t, then, the agent's regret for not having chosen action A is defined as the difference between two terms: the average payoff she would have obtained had she chosen a in periods 1 through to t, and the average payoff she actually obtained during those periods. Young defines an optimal regret-based strategy for this repeated decision problem: it satisfies a no-regret criterion if it ensures that for any sequence of action feedbacks, the agent's regret for each of his actions becomes non-positive as t approaches infinity, all other things being equal.

Some notable contributions made this stylized typology of regret and related emotions fit the investigation of underlying neurobiological mechanisms. We discuss them in the next section. By borrowing experimental paradigms from experimental decision-theory, neuroscientists indeed uncover specific mechanisms associated with the way repeated emotions are optimally biased by regret aversion. One of our concerns is to assess to

what extent these uncovered neurobiological mechanisms correspond to the more stylized notion of regret that has been integrated in some decision-theoretical framework in the view of formalizing how anticipated regret-based learning happens to be an optimal decisional heuristic.

2 THE NEUROBIOLOGICAL BASIS OF REGRET

Damasio (2008) has largely documented the effect of some bilateral lesion of the ventral medial prefrontal cortex on regret aversion driven decision-making. He and his colleagues have studied several cohorts of patients who, post-lesion, display deep difficulties in planning their life, establishing friendly associations, finding business partners, avoiding financial losses, keeping a stable occupation, refraining from certain impulsions and profanities. These behavioral patterns are in neat contrast with these subjects' profiles before the lesion. However the lesion has left unscathed the cognitive abilities: normal intelligence, linguistic understanding, and memory, normal visual, hearing and tactile acuity (Bechara et al. 2000). What essentially differs before and after the brain accident is the decision-making process which has become long and intricate, with all sorts of alternatives entertained and pondered, leading to choices which are found difficult to make and most often disadvantageous. When such choices are repeated, no learning apparently occurs, no lesson of bad past experiences is taken and consistency in suboptimal behavior is observed. This main difference affecting decision-making has been probed on a specific task, called the Iowa gambling task (IGT). Behavioral responses on this task were associated with a measure of variation of the physiological skin conductance response (SCR) and cardiac pace, considered as the main somatic markers of emotional states.[1]

In the IGT, participants face four decks of cards from which they can freely pick cards one after another. They know nothing about the relative value of the decks except that they are not equivalent. So, they must learn about this difference, which amounts clearly to a learning task. Unbeknown to them, the game will stop after 100 cards have been turned up. The decks differ in the variance between gains and long-term profit they present. Decks C and D present a small spread of value (small gains and small losses) to an extent that makes them profitable if the participant sticks to them. Decks A and B embed a few attractive large gains but also large losses such that sticking to them surely makes the participant lose his or her initial endowment. Control subjects, after having explored for a short while Decks A and B, turn and keep on playing on Decks C and D. Ventral medial patients stay on Decks A and B and ask for credit when their endowment happens to be exhausted in the middle of the game. Besides this behavioral particularity, patients exhibit a special physiological pattern compared with controls: they fail to exemplify the somatic markers that induce healthy subjects to avoid negative consequence choices in favor of optimal decision-making. This neurobiological grounding of corrective anticipatory behavior seems a key element of more explicit and cognitively driven regret-based learning processes.

Ventral medial patients seem unable to relate together current actions, expectations and past failures. Only the internal building of this temporal binding between past, present and future is likely to sustain the process of regret-based learning guiding repeated decisions towards optimal payoffs. They also seem to be unable to evoke emotions and to make

them efficient mechanisms in action. Indeed, they are not deprived of all emotions and can abstractly judge that a situation (or an image or a fantasy) with a horrid component should trigger in them some felt negative emotion, but this emotion does not occur. They present the converse dissociation that the neuropsychologist Brenda Milner (1962) had observed with dorsal-lateral and hippocampal patients, who do the right thing but cannot verbalize it. The generation of this signal and its incorporation into executive function is an efficient mediation in decision-making. This signal amounts to an internal bias unconsciously diverting decisions from bad outcomes before it reaches the consciousness threshold, although this point has been contradicted by several authors (see, in particular, Persaud et al. 2007). Whether or not this signal is efficient before or after it reaches the individual's consciousness, it is instrumental in defining anticipated regret as a mechanism whose cognitive and behavioral role is not independent of an embodied emotional alert system.

The underlying cause of the decisional deficiency of ventral-medial patients is therefore, according to Damasio, a failed activation of covert emotional signals which are supposed to bias decision in a favorable direction in the long run. Damasio has, through his implementation of the IGT and the implicit role of SCR, made popular the view that the conscious explicit knowledge of preferences and choice-criteria is not enough to generate optimal decision behavior. Decision processes in the brain are distinct from other cognitive abilities governed by frontal lobes (for example, work-memory and responses inhibition) in the sense that they directly plunge in visceral pre-executive mechanisms associated with emotional autonomous arousal. More has to be said on how a *post hoc* experience of disappointment can change smoothly into an *ex ante* regret-aversive optimal behavior. We find some possible explanation when considering Damasio's distinction between two types of internal signals (Damasio 2008). First, a genuine somatic loop generating 'primary' signals is triggered when individuals face choices under uncertainty and ambiguity. Second, a para-somatic loop can be activated by a mental representation of somatic states (consisting in cognitive states in which the subject simulates his being in a primary emotional state). This loop is selected by choices which, through previous repetitions of the similar situation, looms as quasi-certain or inevitable consequences. The transition from one loop to the other is driven by regret learning and, as we see, amounts to a deep change in the perception of the decision-theoretical context, from uncertainty to quasi-certainty.

The study of this transition has given rise to several studies of what brain mechanisms help us adapt to different decisional structures. The fact that the choices are under ambiguity, uncertainty or risk is differentially treated by the brain (Hsu et al. 2005); the fact that we tend to systematically violate decision-theoretical axioms that are supposed to prevail in these distinct decisional-structures is also a feature that can be explained by the study of our brain fabric. In that context, regret has been made a paradigmatic case.

For the purpose of studying specifically regret-aversion based decision-making, rather than conceptually and phenomenologically generic somatic markers, the IGT has been modified into a regret gambling task and used is several seminal studies (for example, Camille et al. 2004; Coricelli et al. 2005). In that task participants are invited to choose between two 'wheels of fortune', one on the left, one on the right. They display colored zones corresponding to possible gains or losses. For instance, in one typical choice, if subjects choose the gamble on the left, they might win €200 with 20 percent probability

or lose €50 with 80 percent probability; if they choose the gamble on the right, they might win or lose €50 with equal probabilities. The regret gambling task differs from the IGT in that it implements two contextual conditions in terms of feedback provided. Partial feedback shows only the outcome of the chosen gamble; to that extent it amounts to IGT and participants can be disappointed given their expectation that the needle stops on a positive zone of the wheel. Complete feedback allows for a comparison between the consequence of participants' choice and that of the foregone option, eliciting possible regret or relief. Physiological responses (skin conductance responses), choice behavior and brain activity are influenced by these different levels of feedback.

Coricelli et al. (2005) have shown that the same brain areas are activated when the brain faces a certain choice situation, before a decision is made, as when it processed the outcomes of similar choices over past repetitions. Precisely, the orbital frontal cortex and the amygdala mediate how past regret history biases subjects towards minimizing regret across similar choice situations in anticipation of its possible consequences. This result is consistent with Damasio's result, according to which ventral medial structures support the integration between cognitive and emotional components of the entire process of decision-making. Besides the bottom-up mechanisms that make emotions inflect decisions in an optimal sense, the orbital frontal cortex specifically uses a top-down process in which cognitive components, such as counterfactual thinking, modulate emotion.

This complex, double-looped, relation between cognition and emotion has been modeled by evolutionary and behavioral responses. However, such a lesson from neurobiology about the adaptive value of regret stresses the tension between the construal of regret in biology and in decision-theory. We proposed a study of the Allais paradox with ventral medial lesions to explore this tension.

Allais (1953) showed that people tended to exhibit inconsistent choice patterns when presented with pairs of options that involved a contrast between quasi-certain and risky options (see Table 11.2).

The presentation of the Allais paradox in Table 11.2 contrasts a pair of choices among pairs of lotteries. The individual is first invited to choose between Lottery A and Lottery B. He is then confronted with a list of probabilities of obtaining certain payoffs, as in every classical lottery. We can see, for instance, that in Lottery A and Lottery B, he has the same chance (89 percent) of obtaining €500 000. Likewise when confronted with the other choice between Lottery and Lottery D, he has the same 89 percent of winning nothing across the two then concerned lotteries. If the subject rationally applied von Neumann and Morgenstern's axiom of independence (von Neumann and Morgenstern 1944) which states that a choice between two options should be independent of what is

Table 11.2 Matrix of the Allais paradox

Lotteries	Probability of alternative states of nature S1, S2, S3		
	S1: 0.01	S2: 0.10	S3: 0.89
Lottery A	€500 000	€500 000	€500 000
Lottery B	€0	€2 500 000	€500 000
Lottery C	€500 000	€500 000	€0
Lottery D	€0	€2 500 000	€0

common (in terms of both payoffs and the probability of their realization, which is clearly the case for the fourth column of the table when we consider alternatively A and B and then C and D) between the options, he should realize that the pairs of lotteries A and C and B and D actually present the same contingencies. This lack of application of such an independence axiom is what makes the subject reverse his choice, without realizing most of the time that he does so, across the two pairs of choices.

Most of the time, a same individual will tend to prefer A to B and at the same time, without realizing any reversal in her preferences, will tend to prefer D to C. In order to grasp the implicit violation of the independence axiom presented by this preference reversal, please delete the last column of the table, which presents common consequences to be bracketed, and now realize how A ó C and B ó D. Regret theory provides a simple explanation of Allais's paradox. A person who has chosen option B has, if state of nature S1 materializes, strong reasons to regret his or her choice. A subject who has chosen option D would have much weaker reasons to regret his or her choice in the case of S1. When regret is taken into consideration, it seems quite reasonable to prefer A to B and D to C.

Several psychological mechanisms have been hypothetically suggested to account for this type of preference reversal, among which the attractiveness of sure gains and the anticipation of regret if those sure gains would have been forgone and yet realized. The bottom line is that an emotional disposition towards possible future outcomes is involved in the Allais paradox. We tested this hypothesis on a population of patients suffering from behavioral variant frontotemporal dementia (bvFTD), a clinical population known to present ventromedial prefrontal cortex dysfunctions and deficits in experiencing emotional deficit in decision-tasks. We contrasted this group to matched controls and patients with Alzheimer disease (AD) who had no ventromedial prefrontal atrophy. Our results showed a drastic diminution of Allaisian behavior among bvFTD patients by contrast with controls and AD patients. We concluded that prefrontal regions are crucial in the production of a behavior that typically stands in contradiction with a basic axiom of rational decision. By contrast, impaired emotional mechanisms ironically produce hyper-rational (non-Allaisian) behavior in bvFTD patients (see Bertoux et al. 2013).

Decision-theory aims to provide an axiomatic – and thereby in principle intuitive – basis upon which we can assess whether actual choices and repeated decision patterns comply with norms of rationality these axioms are supposed to encapsulate. When these patterns deviate from what logically follows from axioms, we would be alternatively tempted to weaken the latter for the sake of psychological realism or discard evidence on behalf of a principled incommensurability between the descriptive and normative levels. Regret-based decision-theory is a unique attempt, in the recent history of decision-theory, to combine these opposed tendencies, in a sort of reflexive equilibrium approach that would jointly increases the intuitiveness of the axiomatic basis and the cognitive adequacy of the proposed theory.

3 REGRET IN DECISION-THEORY

The Allais paradox gave rise to alternative decision-theoretic accounts. One explanation for the A-D pattern is that decision-makers anticipate regret if they choose B and find themselves in the state of nature S1. Note that at this juncture two comparisons with the

realized outcome are possible which can give rise to two distinct emotions, two forms of regret if one wishes. Depending on information about counterfactual outcomes or states of nature, the unfortunate decision-maker can express two forms of regret. Most naturally, he can regret his own choice B, since the state of affairs S1 has been the case and he won nothing. Had he chosen choice A he would have won a certain €500 000. However, not regretting his choice B, he could deplore his lack of luck and the fact that neither S2 nor S3 had been the case. To our best knowledge these two possible attitudes and types of regret when a risky decision has been made have not been studied.

However, if that choice were repeated, it would be contrary to a rational regret-based decision to avoid B, which presents higher than expected utility, because there would be no grounded reason to think that the 'universe' is fatally stuck to the actualization of S1 (if it were, why would we speak of S2 and S3 in the first place and why would we have attributed the probability 0.01 to S1?). *Per absurdum*, we would systematically be deterred from choosing B, in a repeated sequence of choices, on the basis of anticipated regret if that individual either would have grown extreme pessimism or, which amounts to the same, developed a distorted view of probabilities. This remark on the contrast of the relevance of taking into account regret in a single-choice versus repeated-choices situation makes the picture of how regret should enter into decision-theory more complex than at first sight. Regret-theory has been formalized to account for comparisons between actual and counterfactual outcomes within a single state of nature or 'world'. Regret is relevant in that single world, as expressed through these introductory terms by Suhonen (2007, p. 11, emphasis added):

> The central idea behind regret theory is that, when making decisions, individuals take into account not only the consequences they might experience as a result of the action chosen, but also how each consequence compares with what they would have experienced *under the same state of the world* had they chosen differently . . . Then the overall level of satisfaction derived is a combination of the basic utility of the consequence actually experienced, and some decrement or increment of utility due to 'regret' or 'rejoicing'.

In standard expected utility theory a prospect is evaluated according to the utility of each outcome irrespective of what the other possible outcomes can be. This is strictly forward-looking and consequentialist. As soon as an individual looks to past decisions to base his present choice on them or, more complexly, anticipate a future backward-looking state of mind in which he anticipates he will be regretting the present decision he is liable to make, he immediately ceases to be strictly deciding along consequentialist guidelines. To incorporate such backward-looking attitudes in decision-making, leads us to adopt a non-standard expected utility theory. For instance, an individual may wish to avoid uncertainty, or an individual may not be able to evaluate single payoffs per se but only by comparison with other possible outcomes, his mind being fit to reference points and relative status rather than to processing absolute values. Under a narrow Savagean interpretation of the Allais paradox (Savage 1954 [1972], consequences are identified with monetary payoffs. Under this restriction, expected utility theory is violated by most individuals (including Savage, according to the legend). Under a broader interpretation of what consequences are, or, equivalently, of what a decision-process amounts to, such as that provided by regret-theory, no violation exists. This way out may appear less than satisfactory, though once we relax axiomatic constraints, every type of decisional pattern

can be interpreted as satisfying some revised state of the axiomatics, emptying the theory of all normative and descriptive content. As Tversky (1975) underlined, because we wish to maximize the predictive power of the theory, we are tempted to adopt a restricted interpretation of utility, such as the identification of outcomes with monetary payoffs. In this respect, we can consider regret-theory (Bell 1982; Loomes and Sugden 1982, 1987a) as an optimal trade-off between axiomatic revision and predictive power, a maximally conservative attempt at deviating from standard expected utility with a view to intuitively account for robust behavioral data. Loomes and Sugden (1987b) have built a model that generates testable prediction and compares with alternative theories, standard or not.

Regret-theory consists of the intertwining of two factors in a single utility function that thereby incorporates two measures of satisfaction: utility of outcomes, as usual, and a quantitative measure of regret. The mixing of the two – which supposes their commensurability and, therefore, a conceptual assimilation of regret to a negative payoff – yields a moderately modified concept of utility. In Bell's terms (1982, p. 963) regret is measured as: 'the difference in value between the assets actually received and the highest level of assets produced by other alternatives'. Tracking this difference across choices is what regret amounts to. This is represented by a two-parameter function $u(x, y)$ where x is the actually received payoff and y the difference just referred to. x and y cannot jointly increase and by construction x is maximal when y is null, which means that in this approach, the payoffs of options to be compared always sum to zero and there is always a dominant choice.

Interestingly, this functional representation, thus interpreted, presents a potential contradiction with another heuristic supposed to make us smart, namely, Simon's satisficing principle (Simon 1956, pp. 129, 136). If I reach a level $\bar{x}$ of payoff above which I do not experience any utility increase, then y can freely increase, in the sense that I could have gotten more than $\bar{x}$, but without the difference $Y - \bar{x}$ any longer generating any regret. The contradiction is swiftly spelled out, at the theoretical level first, if we consider that the use of a minimax-regret heuristic is compatible with the optimal determination of our satisficing threshold: given a certain difference between x and y, we can decide not to take it into account, either because it is too small or because it is too large. In that sense, it is the individual's sensitivity to comparisons and regret they elicit that endogenously defines her satisfaction threshold. We can indeed assume that people are sensitive in a non-linear way to different payoff intervals between what they get and what they could have got. If the different is negligibly small or unrealistically too large, I can cease to be sensitive to the discrepancy between actual and forgone outcome. It is likely that the individual feels regret when the comparison falls between a certain perceivable and conceivable gap, beyond which it appears a vain feeling. In that sense minimization of anticipated regret and satisficing are not incompatible smart decision-making principles. This is consistent with some recent results about the behaviors of maximizers and satisficers with respect to their feeling regret about their decisions (Moyano-Diaz et al. 2014). As the authors of the study point out, a main difficulty in the study of decision-making is precisely the combination of the two coexisting partially incoherent aspects and dimensions that are maximization and satisfaction. Regret can be seen as playing a subtle mediational role between these two dimensions. Regret is more than an emotional reaction against bad consequences; it is also an internal transformation, as we have seen, of these bad consequences into an anticipatory process. Regret is then inherent to its future avoidance and is compatible with maximizing utility. As Schwartz et al. (2002) found and is reported by

Moyano-Diaz and his colleagues, maximizers tend to engage more often than satisficers in social comparisons and are more affected by them. Regret is for them a driving force towards optimization. Maximizing is not blind forward-looking or full-fledged consequentialism, then, as past errors and all alternatives are scrutinized. However, this type of regret-based maximization decision-making style bears a high psychological opportunity cost and potentially generates a lot of continuing frustration. In contrast, satisficers proceed more easily and are satisfied with their good enough option. In that sense, satisficers can be said to minimize the counterproductive use of first-order regret minimization. We then equate Simon's satisficing to second-order minimax-regret in what we consider a fuller account of the psychological cost associated with the presence of bad decisions and the correlative first-order regret they tend to provoke. We could thus envisage a Simon-based regret model in which the individual is likely to experience regret when the psychological cost to do so does not exceed the benefits of correcting his or her present decision in view of future benefits. Admissible regret is thereby endogenously defined because future benefits are themselves bound by the individual's level of satisfaction. When the latter is attained, there is no more valuable motive to admit regret as a reasonable emotion.

This Simonian perspective on the link between satisfaction and regret suggests a deeper analysis of how the different ways of incorporating regret into decision-theory also convey different views of human rationality. In summary, Loomes and Sugden's way is still essentially consequentialist, in the sense that regret is both included in a maximization process and that the functional representation they propose remains fundamentally compatible with a forward-looking attitude. Differently, the short analysis we have provided of the compatibility of satisficing and second-order regret-minimization amounts to a non-consequentialist view, decision-makers deciding now to ignore certain information and consequences of their choice beyond a certain threshold; satisfaction, in the Simonian sense, meaning not only to cease to adopt a utility maximizing attitude but also to cease to make any counterfactual comparison once a certain level of utility is reached. This way of blocking potential feelings of regret emphasizes, by contrast, the role of signals and omens in standard decision-making. We can imagine individuals ready to pay not to receive information about outcomes of forgone decisions. Karlsson and colleagues (2005), in an unpublished study, have documented a very similar phenomenon on financial markets, which they label an 'ostrich effect', people deliberately discarding information about their investments portfolios when markets go down. Regret aversion is seemingly an ordinary feature of decision-making related to a human propensity to respectively seek or avoid positive and negative omens and base our decision at this symbolic level rather than strictly focus on the evaluation of our choices' consequences.

We have studied regret in connection with the Newcomb problem in that perspective. This problem tackles with deep philosophical issues around the nature of rationality, along the dividing line we have discussed above: can we rationally take into account information about our choices that in fact does not change the way consequences will be realized. Is there a way to vindicate the fact that, in some cases, we are sensitive to consequentially irrelevant information? This dividing line among decision-theorists – only among those of a philosophical bent though – has been labelled in terms of a difference between causal decision-theory (individuals make their choices according to basic stochastic dominance and independence principles) and evidential decision-theory (individuals may legitimately be influenced in their decision-making by symbols or information present in the choice

situation which, in principle, do not affect the consequences) (Joyce 1999). Nozick (1969) devised that paradox of rationality with the explicit purpose of contrasting consequentialist and symbolic forms of rationality. In this problem, two boxes, one opaque, one transparent, are presented to a decision-maker along with the following message:

> Imagine a being with great predictive powers. You are confronted with two boxes: B1 and B2. B1 is opaque and B2 is transparent, you can see that it contains €1. B2 contains €1; B1 contains either €10 or nothing. You may choose B1 alone or B1 and B2 together. If the being predicts that you choose both boxes, he does not put anything in B1; if he predicts that you choose B1 only, he puts C10 in B1. => What should you choose?

We had hypothesized that if this choice of alternatives, as Nozick thinks, coincides with different types of rationality, they could also elicit different levels of confidence in our choices. If I really believe in God, I might be inclined to accept a certain level of non-consequentialism in my choices. However, disappointment can be greater in that case than if I had made a purely consequentialist choice (ignoring the omen) followed by a bad outcome. I therefore considered that regret, when I realized what I could have got had I made the other choice, is modulated by the type of rationality implied by our choices (Bourgeois-Gironde 2010).

Let us label individuals one-boxers and two-boxers according to their decisions in the Newcomb problem (Nozick 1969). Two-boxers go against the prediction. The decision-criteria they presumably follow have been characterized, as we did, as consequentialist, but also, in philosophical parlance, as we reminded above, as 'causalist', by contrast with 'evidentialist'. Two-boxers thus apparently exhibit a higher autonomy, that is, a higher level of decisiveness, in their choices than do one-boxers, although the latter's faith in the omniscient predictor can also yield a high level of decisional confidence (think of Pascal's wager; Pascal 1897). Integrating the decision-criteria predictions, signs and symbolic value may not be altogether irrational (Nozick 1994). It is pervasive enough, as, for example, in convincing ourselves of our good health or of the influence of our vote in national elections by going to vote, by accomplishing acts that amount to generate self-manipulated positive signals (Quattrone and Tversky 1988).

Shafir and Tversky (1992) have run the first empirical investigation of Newcomb problems. They submitted to their subjects a Newcomb problem. Their cover story was that 'a program developed at MIT was applied during the entire experimental session to analyze the pattern of your preferences, and predict your choice (one or two boxes) with 85% accuracy' (Shafir and Tversky 1992, p. 461). Although it was obvious that no *deus ex machina* intervened at the moment of choice, most experimental subjects opted for the single opaque box rather than for the dominant two-boxes strategy. It is as if they believed that by declining to take the money in box B2, they could change the amount of money already deposited in box B1. Adding on their test, we measured whether regret was different when negative outcomes are revealed to one-boxers and two-boxers. We observed – by means of a retrospective measure of satisfaction on a five-point Likert scale – that one-boxers, when facing negative outcomes, experience a significantly greater amount of regret than do two-boxers in the same situation. This is due, we speculate, to the lesser decisiveness or autonomy with which those choices are made, in spite of their greater faithfulness to the prediction. If a difference emerges between types of decision and amount of regret in the Newcomb problem, this can be considered as a step toward

a better understanding of how regret taps into rational antecedents of choices and can be modulated by competing criteria of rationality.

4 REGRET AS A COORDINATION DEVICE AND A SOCIAL MECHANISM

Bob wants to go to the opera with Ann tonight. However, in their last discussion, they split on a doubt about what they would do; Ann definitely seemed to wish to please Bob and to agree to go to the opera, although she had declared her preference for the boxing match in another part of town. When they left, Bob said clumsily but audibly that he would like to please her too. In the confusion they omitted to give each other their mobile numbers. Now Bob goes to the boxing match, and does not find Ann. In another scenario he goes to the opera but learns the next day that Ann had opted to go to the boxing match, having understood that Bob would join her there. One could say that an *ex ante post hoc* regret-minimizing based decision would have induced Bob to go to the fight, as he would have had the moral comfort to have tried to please Ann retrospectively. However, if Ann follows a similar strategy, they miss each other and fail to go out together to their joint detriment.

Imagine this situation is repeated every day, with the same level of conversational confusion and omission of electronic devices coordination, by Bob and Ann. It is as if they both lived in 'groundhog day' with the characteristic fact that some external and internal elements (such as their inability to correct their spontaneous lack of coordination) fatally befell them. However, they can change their decision every day. There are many ways for them to get out of their predicament. They still have available external and internal resorts. They can use a binary coordinative device, like tossing a coin, or look at the sky, whether it is sunny or overcast, and silently fit their behavior, after a few learning trials, on this conventional signal. Or they can use regret, which is internal, on the hypothesis that they tend to feel the same, which was in the premise of the argument. The use of the coin, or the sky, or a traffic-light for that matter, is a coordinative device that leads to a correlated equilibrium (Aumann 1974). A correlated equilibrium arises in a situation where mis-coordination is likely, owing to several present Nash equilibria leading to suboptimal effects, and when players resort to a set of received signals or instructions by a neutral referee. A correlated equilibrium, technically, is a probability distribution over the players' space of strategies realized by the referee (or by nature) and from which no player has a unilateral interest to deviate. Hart and Mas-Collel (2000) have shown in what sense regret is an adaptive heuristic in reaching correlated equilibria.

Basing a decision on the one that simply minimizes our regret, in the 'battle of the sexes' between Bob and Ann we have described previously, could apparently lead to persistent mis-coordination. If one pleases the other in the same way, their paths will continue to diverge, but this could be solved by using the following heuristic: 'Switch next period to a different action with a probability that is proportional to the regret for that action, where regret is defined as the increase in payoff had such a change always been made in the past.' (Hart 2005, p. 1405). This works because it dynamically removes the players from a single-handed strategy (that would consist, for example, of blindly pleasing the other). Players engage in a learning dynamics that will make sources of regret endogenously

evolve and, thereby, by individually, but jointly, directing their effort to minimize this regret, happen to reach a correlated equilibrium in an efficient way. Regret owing to mere failure of coordination (not simply because of own fault or misplaced benevolence) will progressively guide the choice of strategies by pondering the probability of which of the strategies is played. It means that both players end up feeling the same type of regret based on their suboptimal payoffs, whatever the personal motives that previously led them to mis-coordinate. Interestingly, jointly minimized regret, although an internal endeavor and learning mechanism, plays the role of a public coordination device, avoiding any need for external communication or objective means of coordination, as is required in other ways of reaching correlated equilibrium.

The use of regret consists represents a smart heuristic in the sense that it allows players to eschew the computation of highly complex objects such as repeated games strategies and beliefs. By means of Hart's heuristics they can simply trade-off between past payoffs associated with a given course of action and match past frequency of success with the probability with which they will stick to this course of action. More precisely, regret is a 'smart' heuristic in the sense that it is cognitively parsimonious (to match past payoffs and future actions probabilities is relatively easy), but also in the sense that it is not dumb or fully blind either, as it requires a certain level of freedom of choice and self-modulation of the weight the individual wants to give to this signal. It then requires a certain degree of rationality. In evolutionary dynamics, by contrast with learning dynamics such as the use of a matching-regret heuristic, agents do not have to exhibit any level of rationality, as their phenotype (observable behavior) is deterministically dictated by their genotype entailing that they have no leeway to modulate their strategies and learning mechanism. They play relatively fixed actions that aggregate into group behavior. What can be called rational or irrational in that context is the collective dynamics of the population to the extent that it leads to optimal steady states. Our next question, then, is to ask to what extent assessments of collective rationality can be informed by regret-based decisional patterns at the individual level?

Voting procedures are paramount social mechanisms that display this discrepancy between individual and collective rationality. It can go both ways. The paradox of voting is a typical instance of collective rationality (the possibility of an optimal social choice through aggregation of individual preferences) not being supported by individual rationality (in large groups, it is 'irrational', when we think in costs-benefits terms, to pay the cost of going to the voting booth). Arrow's impossibility theorem (Arrow 1951 [1963]), on the other hand, is a deep illustration of how individual rationally structured preferences (with respect to their transitivity) do not necessarily aggregate into a transitive social preference.

A solution of the paradox of voting has been proposed by Ferejohn and Fiorina (1974) in terms of the minimax regret criterion. Voters choose the action that yields a minimal regret in a worst case scenario. This implies a form of strategic voting which can seem contradictory with the fact that, if voters are aware that their vote is unlikely to be pivotal, they could still vote sincerely. The situation is far from being unrealistic. Also, collective regret is likely to arise in that situation. Regret being elicited by the possibility of comparing what one has got from what one could have got depends on the possibility of counterfactual learning at some point of the democratic process. The 2007 elimination of candidate Lionel Jospin in the first round of the 2007 French presidential

election may have aroused such an emotion among the voters for the minor left candidate, Taubira, leading to the far-right candidate Le Pen's presence in the second round. The use of alternative voting procedures may not only have led to another result, but perhaps also to lesser pangs of regret felt by some of Taubira's supporters (Baujard et al. 2014). Uninominal majority voting, approval voting, and evaluative voting differ in three comparable respects: (1) they are more or less expressive, in the sense that voters can convey more or less fine information about their preference in selecting their options; (2) it is more or less polarized, in the sense that negative feeling towards a candidate can be strengthened in evaluative voting if negative grades are allowed; (3) it can be more or less easily strategized. The parameters inherent to the voting procedure can be associated with its varying susceptibility to regret. If we have the opportunity to express a fuller and finer choice without jeopardizing the election of a consensual candidate (which is the case by use of approval voting in particular), regret, in case of non-success, will presumably be minimized.

Tideman (1985) extended the minimax regret model of voting by borrowing from the Sugden and Loomes' framework we discussed in section 3. He adds the concept of remorse and elation to the model, which are 'emotions that arise as a consequence of being responsible for one's circumstances by one's own actions' (Todeman 1985, p. 103). The key, there, is this feeling of responsibility which is a constitutive element of regret: losses and gains are accentuated if we are or feel responsible for the feared result. Guilt drives regret, even in a context where there is no objective influence of the voter on the outcome. It disproportionately distorts it and might explain high levels of voter turnout. Can it be smart in this social and political context?

Emotions are an important element of the political game and influence behavior (individual or collective) (Groenendyk 2011). However, what has been less studied is how emotions endogenously depend on certain features of given democratic structures, in terms of choice procedures, aggregative mechanisms and informational filters and feedbacks. Understanding how the mechanisms of social choice generate by themselves emotional states and flux is crucial in view of the democratic regulation of the political game: democratic leaders do not want their institutions to be undermined by extreme political affects nourished by their constituencies. Several levels of analysis are relevant for this still widely open set of issues: (1) mechanisms of choice – essentially how the procedure used for voting and the aggregative mechanism associated with those rules trigger positive or negative emotions; (2) information and feedbacks about the political process and its results (pools and so on), on the basis on which payoffs comparison can be made and an adaptive regret heuristic launched; and (3) timing of choice – frequency of elections, possibility of voicing popular opinion in regular moments and channels – determining fluctuating emotional states in the population of voters.

At a more general level, we could wish for a society that maximizes consensus, by minimizing the distance between the social choice and each individual vote (see Kemeny 1959) and that also minimizes regret in terms of minimizing individual loss functions. This is not strictly equivalent, and some dynamic emotional fluctuations in democracy might be due to the interplay between those two minimization functions. More generally, the issue is the analysis of how emotional dynamics in democracy might depend on fine structural choices on aggregative and informational political mechanisms. Again, we point here at a possible discrepancy between social consensus thus defined and individuals' psychological

factors such as regret or satisfaction with respect to the effective social choice. Each individual feels more or less satisfied with the current social choice (for example, the result of the last election). Ignoring, for the sake of a simpler presentation, dynamic effects occurring in the course of office terms, these levels of regret or satisfaction can be envisioned, as a first approximation, as products of loss functions (minimax regret) for each individuals. From a computational point of view the aggregation of individual loss functions in the population and the measure of the distance between each individual preference of that population and the social choice are not identical.

Incorporating individual levels of regret as a parameter of social satisfaction with respect to some social choice function is then an attempt at combining collective and individual rationality. It also potentially anchors back social choice mechanisms into adaptive heuristics upon which real individuals tend to make decisions, combining emotional and cognitive abilities, and fine-tuning our biological and social fabrics.

5 CONCLUSION

Anticipated regret is one of the most efficient heuristics that we can use in order to avoid from suboptimal decision-making. It has been incorporated in decision-theory at an axiomatic level, both in individual decision-making and in interactive strategic situations. Moreover, it has been demonstrated an efficient learning mechanism, leading to optimal decision-making, and coordinative device in multiple equilibria game-theoretical contexts. Regret-theory is nevertheless compatible with bounded rationality paradigms such as Simon's satisficing principle; the latter involving a form of second-order modulation of the amount of regret that an individual can reasonably experience in order to guide his or her decisions towards a satisfaction threshold. This view seems in agreement with what recent brain-imaging studies have taught us about the neurobiology of regret. The emotion of regret lies at the junction of the processing of aversive states and of the cognitive anticipation of future outcomes of the individual's actions. For this set of reasons, we consider regret to be one of the best candidates in a view to unify biological and decision-theoretical approaches to optimally bounded decision-making.

NOTE

1. Somatic markers such as perspiration, hence skin conductance of body parts such as fingertips, or heartbeats, pulsations, and so on form a particular class of measurable bodily states that Damasio and Bechara in a series of influential studies in the 1990s have shown to be correlated with so-called secondary emotions. The latter are feelings that have been associated, through past repeated experiences, to the learning and anticipation of future outcomes in certain typical choice situations. When a somatic marker is associated with a particular negative outcome it functions as an alarm bell and is a reliable signal. It is convenient to understand anticipated regret in the framework of this 'somatic marker hypothesis'. Interestingly these predictive somatic markers can be effective without fully arising to consciousness, making them an automatic self-corrective mechanism. (For another type of experimental approach on feelings of errors and their predictive and corrective roles see Gangemi et al. 2015.)

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