INFORMATION SOURCE'S RELIABILITY

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Gérard Mondello

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Gérard Mondello[*]

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Summary

This paper studies the impact of unreliable information sources on the decision process under ambiguity. Using a modified Ellsberg framework, it compares two types of agents: one is a Savage expected utility maximizer and the other a Neo-Choquet-type expected utility maximizer. This comparison shows that while the former will always conform to the source of information regardless of its level of reliability, the latter will make its choice based on its levels of preference/aversion for ambiguity and its degree of optimism/pessimism. Therefore, this explains why decision-makers may choose randomly when the reliability of the information source is too low.

Keywords: Uncertainty theory, decision theory, ambiguity aversion, Information.

JEL : I1, I18, I19, D80, D81, D83.

[*] Université Côte d'Azur, GREDEG, CNRS, France.
250, rue Albert Einstein
06560 Valbonne, Sophia Antipolis. France
Tel.: + 33-4-93954327-fax:+ 33-4-93653798,
gerard.mondello@univ-cotedazur.fr

0. Introduction

Ambiguity or radical uncertainty (Knight (1921)) arises from events whose outcome is poorly assessed by likelihood of occurrence, or even without known odds. However, uncertainty can also arise from weak, missing, or even contradictory information. Indeed, in a complex world, a decision-maker (DM) receives several conflicting pieces of information and one of his/her tasks is assessing the reliability of both the information and its source before making a choice. For example, when faced with a sudden unknown pandemic, the DM ignores whether the epidemic is due to a virus or a bacterial genome, how it spreads, the best preventive measures to immediately implement, etc. (Berger et al. (2013)). Each of these different areas receives much information from many different sources. This shows that ambiguity comes either from the impossibility of reaching a precise probability of occurrence (several contradictory causes are put forward to explain a given phenomenon), or from the source of information itself which may be untrustworthy, or, still from both. A reliable source may transmit incomplete or ambiguous information, as may an unreliable one. The difference is that in the first case, only the uncertain phenomenon issue must be considered, while in the second, the source's unreliability adds to ambiguity. These issues apply at both the micro and macro levels. For example, concerning the climate change several decades passed before scientists reached a consensus on the anthropogenic causes of global warming (Weart (2011), Pachauri, et al. (2014)), this, in spite of contradictory scientific and less scientific views.

Some kinds of uncertainty can be verified and learned from, as the work of the IPCC has shown since its inception. Blackwell (1951) compares information systems where differentiated information called "experiences" are evaluated (i.e. the marginal gains of action) and ranked. This framework allows ranking options from the most optimistic to the least optimistic. These situations are called monotonic decision problems. Thus, Blackwell's theorem states that the value of an experiment-I is weakly superior to that of an experiment-II for all expected utility maximizers and all sets of actions if and only if experiment-I is more "Blackwell informative" than experiment-II. This is the case if the former can define the deformation grid of the latter[1]. These are approaches linked to situations where information

[1] For instance, internet and telegraph can send the same message. The accuracy rate of the first means can be 99.9% and only 10% for the other, for instance. In both cases, ambiguity remains, but its order of magnitude is radically different: «*A communication channel with a smaller error probability is more Blackwell-informative. For example, a message sent via email, with an error probability of 1/100, is more informative than a message sent via telegraph, with an error probability of 1/10.* » (Li and Zhou, 2016 p. 20). See also, Lehmann (1988)), (Li and Zhou, 2016), for further extensions.

systems can be ranked as a result of experimentation or interpretation of a signal such as, for example, revenues tied to financial securities, marketing data for innovative products from databases, information resources, etc.

Such rankings are not possible in other situations where decision-making is based on cursory and little information. The learning phenomena are reduced to their simplest expression, contrary, for instance, to Epstein and Schneider's (2007) where learning involves repetition that should avoid irrational choices[2].

The above streams involve the formation of data sets and/or the repetition of experiments. That is not the direction this paper takes here. Instead, we consider conjectures where the quality of the source of information is low and, therefore, the given information is questionable without the possibility of repetition. For example, in Ellsberg's (1961) representation consisting of two urns and balls of two colors each, the information about the proportion of balls in one of the boxes (urn-1) is given and certain. So, in the first urn, the proportion of red and black balls is known with certainty, while in the second urn, this proportion is unknown. The decision maker does not question the information source integrity, because it is undisputable. However, in the real world, information is not as accurate and data may be missing. This is especially true in an emergency or critical situations characterized by faulty information sources.

In the uncertainty literature, information leads to changes in agents' beliefs when new events occur, as noted by (Pires 2002 p.13)

" *One issue which is not addressed in the previous models is the updating of beliefs and preferences as new information arrives*." Much of the contemporary literature shows the complexity of the decision-making mechanism facing radical uncertainty. Indeed, it is impossible to achieve updating using Savage's Bayesian conditional process (Ghirardato (2002)). Under radical uncertainty, revising preferences is more complex and can take different forms[3]. An updating of beliefs involves using *updating rules,* "*that specify for any preference relation and for any event of a measurable partition of the set of states of the world, what is the preference relation once that event is known to have occurred*" Pires (2002 p. 139).

[2] See (Ju and Miao 2012)'s bibliography for further extensions.
[3] For instance, The literature distinguishes at least four of them. Three were identified by Eichberger, Grant and Kelsey (2010) and a fourth by Dominiak and Lefort (2013):

- The optimistic revision rule (Gilboa and Schmeidler (1993)),
- The pessimistic revision (Dempster (1968) and Shafer (1976)),
- The generalized Bayesian revision rule (Jaffrey (1992)),
- The neo-Bayesian constant revision rule by Dominiak-Lefort (2013).

However, this contribution will not follow the arrival of information path and will limit itself to analyzing the consequences of the uncertainty generated by the information sources. Its purpose is to show how the information sources' unreliability influences the agents' beliefs and how they manage this added ambiguity to ambiguity. To address this issue, we keep Ellsberg's example with two ballot boxes and two colors (Ellsberg (1961)). We simply change the basic framework by considering that the source of information that was initially safe, will be faulty.

Several causes can make information unreliable. Inaccurate information can either come from insufficient knowledge of the phenomenon considered, or from the source of information itself. In the first case, reliable sources may provide contradictory information. But also, sometimes, the information medium itself is dubious (information sources financed by industrial or political lobbies, propaganda, for example). Therefore, the unreliability of the source leads to adding uncertainty to the existing ambiguity.

This article focuses on the importance of the DM's beliefs before choosing. We highlight the question by an example in section one. Then, in sections two and three, we contrast two ways of thinking. The first is based on Savage rationality where risk-neutral agents follow their primary economic interest based on their gain expectation. Section 2 below shows that this leads to irrational behavior because, using this rationality, regardless of the credibility of the information source (even the weakest level), the DM will prefer to make the information-induced choice over a random choice. The second way is to refer to recent advances in decision theory concerning ambiguity (section 3). In particular, we will use the methodology of Chateauneuf, Eichberger, and Grant, (2007). This methodology considers knowledge bias, optimistic and pessimistic beliefs, and preference/aversion for ambiguity.

This approach is inspired by (Schmeidler, 1989)) (Schmeidler and Gilboa. 1993), (Klibanoff, Marinacci, and Mukerji, 2005), and other authors for mathematical ideas applied to decision theory when the probability of occurrence of events is greater than one. Chateauneuf, Eichberger, and Grant (2007) offer an easier-to-implement analysis based on the work of Wakker (2001). The latter extends these notions to arbitrary events whose outcomes are ranked and characterize optimistic and pessimistic attitudes. They change Choquet's Expected Utility Model (CEU) by introducing the weighting of the highest and lowest outcomes, combined with the usual expected gain or utility. There, concave capacities show optimistic attitudes towards uncertainty, while convex capacities model pessimism. Then, we show that different decision-makers, even perfectly rational ones, can make different choices depending on their level of beliefs which depends on their preference/aversion for ambiguity and their degree of optimism/pessimism.

1. Setting the problem by an illustration

In one episode of the British series MI5, (episode 9, season 1), the MI5 agency faces the following dilemma. A historic IRA leader contacts the MI5 office and offers a tragic deal. Indeed, he claims to have information about a terrorist group close to El-Qaeda that would be plotting an attack on a nuclear power plant on British soil. As a deal, the activist offers to provide full information on this terrorist action in exchange for a complete halt to the tracking of his IRA group for three days. MI5 members are reluctant because they know that the IRA will use this time to carry out a terrorist attack on the London subway. Therefore, MI5 must arbitrate between two potential harms. First, an El-Qaeda attack that would kill thousands and sterilize much of the country, or second, an assault on the subway that would kill fewer people but disrupt the security services for a long time. This dilemma divides the members of MI5. His supervisor (Harry) thinks that the information is worthless because of the unreliability of the IRA informant he knows well. His subordinates are convinced of the opposite. The only thing that both sides agree on is that the IRA terrorists will commit the attack on the London Underground with certainty. Then, the dilemma can be described as follows:

1) Let be B the source. Believing him and accepting its condition leads to two potential situations:

a) Either (B) tells the truth, and MI5 neutralizes the El Qaeda group. However, IRA terrorists will attack the London Underground. The loss would amount to (D_2). (We do not consider the case where, despite the information, the British security services would fail to contain the El Qaeda terrorist action).

b) Or (B) lies, then, the only terrorist attack comes from the IRA's side. Once again the loss amounts to D_2.

2) Do not trust the source (B) and keep monitoring the IRA group to avoid any IRA attack. Then, here again, two possibilities present themselves:

c) (B) tells the truth, then, El Qaeda carries out its nuclear terrorist attack while the London Underground is kept under control. The casualties then amount to D_1, (Where, $D_1 > D_2$). Here $D_2 = 0$.

d) (B) lies, there is no El-Qaeda attack at all, consequently, no losses are to be deplored:
$D_1 = D_2 = 0$.

We can give a better representation of the whole dilemma by using the following notations:

3) Let F the opinion that B is reliable, and $\overline{F}$ that he is not.
4) Then, the choice is either to act (A) (i.e. preventing the El Qaeda's attack but accept the IRA's condition) or $\overline{A}$, staying passive (this means that the MI5 will not pursue the El Qaeda group BUT going on preventing IRA's actions as usual).
5) Believing in B's words does not mean that the latter tells the truth (T), then, B can lie $(\overline{T})$. Being aware of these factors, we can assess each party's expected losses.

Let $L(-)$ the discrete function expressing the losses following the different situations we can meet. It follows that for the Harry's team, $L(-)$ brings the following losses $D \in \{D_{1,}D_2\}$:

1) $L(D|F/A/T) = D_2$

Literally this means: "the loss will be $\{0, D_2\}$ if we believe the source B, which involves "acting" as defined above, and when B tells the truth."

2) $L(D\big|F/A/\overline{T}\big) = D_2$

2) is the result of the fact that B lies. Note that the activist succeeds by his cheating.

3) $L(D\big|F/\overline{A}/\overline{T}\big) =?$

4) $L(D\big|F/\overline{A}/T\big) =?$

The question-mark in 3 and 4 that can be understood only by referring to Harry's beliefs. Indeed, if the agents trust the activist and obey Harry, they will not act, keep on tracking the IRA's activist and the expected loss will be either $L(D\big|F/\overline{A}/T\big) = D_1$, when the activist tell the truth and $L(D\big|F/\overline{A}/\overline{T}\big) = 0$, if not. These results may seem odd, because we also could expect that $L(D\big|F/\overline{A}/\overline{T}\big) = D_2$ or that $L(D\big|F/\overline{A}/T\big) = D_1 + D_2$, but this makes no sense because, this would mean that the agent both do not control the Al Qaeda terrorist group and, furthermore, they break the Harry's orders to control the IRA activists, which is an act of high treason. It follows that when the group decides to follow Harry's order, this is done independently of its own beliefs then:

5) $L(D\big|\overline{F}/\overline{A}/T\big) = L(D\big|F/\overline{A}/T\big) = D_1$, or if the activist does say the truth and,
6) $L(D\big|\overline{F}/\overline{A}/\overline{T}\big) = L(D\big|F/\overline{A}/\overline{T}\big) = 0$ if he lies

This last equality means that for Harry, the activist lies with a probability equal to 1. The dilemma bears on the Harry's team shoulders because if they obey Harry's orders, and if he is right, a null loss 6) is probable. However, this is challenged with the team's opinion that the source says the truth and is credible. This last belief leads to considering that $\{0, D_2\} \succ \{D_1, 0\}$ because first, $D_2 < D_1$

The following writing could simplify by considering that the Harry's team obey his order (Ob) or disobey ($\overline{Ob}$) to it. Then, believing and acting are linked and the above system rewrites as:

1) $L\left(D\middle|\overline{Ob}/T\right) = D_2$
2) $L\left(D\middle|\overline{Ob}/\overline{T}\right) = D_2$
3) $L\left(D\middle|Ob/T\right) = D_1$
4) $L\left(D\middle|Ob/\overline{T}\right) = 0$

Hence, the question comes to matching a sure loss when disobeying (i.e. obtaining "only" D_2), against an uncertain one (i.e. losing either$D_1 (> D_2)$ or nothing 0).

Decision theory solves the question by assigning probabilities of occurrence to the different events, here it could be about the level of responsibility the agents put on the level of reliability of the informant, and the probability of telling the truth. In the present case, unfortunately, this cannot be done, as the situation is unique, i.e. unprecedented. Second, whether or not to obey Harry is a matter of feelings. Note that the MI5's producer of the series did not solve the dilemma because he chose a middle-term solution that consisted in freezing the metro activity after having found where and when the IRA's attack will occur. This means that the dilemma has not been solved.

2. Unreliable information source and Savage utility maximizers

2.1 Setting the problem for Savage Utility maximizers.

To analyze this point, we consider a game where the DM wins \$100 if she draws a red ball from one of two urns consisting of red and black balls in an unknown proportion but each containing K balls. More precisely, the entire game consists of choosing the urn from which she draws a ball and winning if the ball is red. Then, if the DM has no information about the ratio of red to black balls in both urns, except that each contains K balls such that $R_k + B_k = K$ (where R_k stands for red balls and B_k for black ones and index k represents either urn 1 or 2, ($k = 1{,}2$)), then, obviously, the DM can do nothing more than choosing an urn at random.

Now, similarly to Ellsberg (1961)'s framework, suppose that the game-organizer gives, as information, that the red and black balls proportion in urn-1 is known in the following proportion: $(\frac{R_1}{K} = \frac{B_1}{K} = \frac{1}{2})$, (with $R_1 + B_1 = \tilde{R}_2 + \tilde{B}_2 = K$) while the proportion remains unknown in urn-2 $\left(\tilde{R}_2, \tilde{B}_2\right)$ (where the "tilde $\simeq$" stands for unknown number or proportion related to K). Here, the information is indisputable because the source is supposed perfectly safe. Playing twice and changing the winning order on the second run meets the usual Ellsberg framework.

Now, we modify Ellsberg's framework by considering that the source of information is no longer reliable. So, the proportion of red and black balls in urn-1 is either known or as unknown as in urn-2. If the now unreliable source tells the truth with a probability $\gamma, (1 > \gamma \geq 0)$), i.e; the information says that inside urn-1, the proportion of red balls is $\frac{R_1}{K}$ and black balls $\frac{B_1}{K}$ with probability γ, and unknown $\left(\frac{\tilde{R}_1}{K}, \frac{\tilde{B}_1}{K}\right)$ with probability $(1 - \gamma)$. The question is then, how this uncertain information may affect the DM's choice?

It follows that, if the DM believes the information source, the DM faces, for instance, the following lottery L_1, such that:

$$L_1 = \{\$100, p = 1/2; 0, (1 - p) = 1/2\}$$

However, the information is only reliable with a probability γ, $(1 > \gamma \geq 0)$, and faulty with probability $(1 - \gamma)$, this lottery's dual is a range of alternatives such that if K is the total number of balls in urn 1 then, $\tilde{R}_1$ and $\tilde{B}_1$ are respectively the unknown number of red and black balls in urn-1 if the source is wrong $(\tilde{R}_1 + \tilde{B}_1 = K)$. Thus, the probability of drawing a red ball is unknown and is included in a set of possibilities corresponding to the potential lotteries L_k where $\{k = 1 \ldots K\}$ that may be formed in urn-1 if the source fails. Hence, saying that the information source is safe with a probability of γ considering L_1 comes to say that this challenges the lottery L_k potential loteries with a probability of $(1 - \gamma)$ in urn 1. Indeed, by choosing urn-1, the DM is unsure about the proportion in this urn conversely to the "standard" Ellsberg framework. What we show below is that by disposing of this information, the DM can either follow it or not.

2.2 Unreliable information source and a Savage DM

Now we study the formal behavior of a Savage-agent type informed by an unreliable source. Before going on, we need to precise some analytic factors.

2.2.1 Some preliminary considerations

Under the usual conditions of Ellsberg's framework, the DM chooses either urn-1 or urn-2. She does not make public her motivation. Here, now, it is important to know whether her choice is random or not. Therefore, we introduce a fictitious device where, before her choice, the DM must announce to the organizer she chooses either randomly between both urns, or if her choice follows the source information. Then, if the choice is random, it means that the DM will draw the ball in a kind of "head and tail" process. A non-random choice is the result of a conscious selection that involves the DM being convinced of the credibility of the information source. As an assumption, we consider the case where the proportion of red balls is higher or equal to the black ball in this urn.

Before going further, we do not expect that, when faced with an experiment, all agents will behave in the same way. Some will conform to the information pattern, others will not. In the subsection below, we will examine the conditions that lead agents to play according to the information received and the agents that do not.

2.2.2 The Savage representation

Let us consider the potential lotteries $L_i, (i \in I)$ with I their potential number $\mathcal{L}$ is the set of lotteries ($L_i \in \mathcal{L}$). The DM's preference relation " $\gtrsim$ " where "$\sim$" is indifference and " $\succ$ " strict preference. The game focuses on the first step of the Ellsberg's game. This relationship meets the following standard axioms:

Axiom 1 (*Weak-order*): i), ($\forall i, j,\ L_{\mathrm{i}} \gtrsim L_j$or $L_{\mathrm{j}} \gtrsim L_i$), ii) reflexivity, $L_{\mathrm{i}} \gtrsim L_i$, iii) transitivity, ($\forall i, j, s,\ L_{\mathrm{i}} \gtrsim L_j, L_{\mathrm{j}} \gtrsim L_s$ involves that $L_{\mathrm{i}} \gtrsim L_s$).

Axiom 2 (*Continuity, or the sure thing principle):* $\gtrsim$ is continue, if for all lotteries, L_i, L_j, L_ssuch that $L_i \succ L_j \succ L_s$, $\forall \alpha, \beta$ such that $\alpha, \beta \in [0;1]$, $\alpha L_i + (1-\alpha) L_s \succ L_j \succ \beta L_i + (1-\beta) L_s$

Axiom 3 (*Independence*): " $\gtrsim$ " is independent, if for lotteries L_i, L_j, L_s, $L_{\mathrm{i}} \gtrsim L_j$ involves that $\forall \alpha$, $\alpha \in [0;1]$, $\alpha L_i + (1-\alpha) L_s \gtrsim \alpha L_j + (1-\alpha) L_s$.

These axioms are standard here. Let also be γ the probability of the information source reliability ($\gamma \in [0,1]$ and $(1-\gamma)$ with $(\gamma + (1-\gamma) = 1)$. Then, if the DM considers that the information source is credible, she considers the lottery L_1 in her calculation as the basis of her present and further calculus. If, on the contrary, she thinks that the information is not credible, choosing urn 1 comes to a random choice and conventionally, this will correspond to the lottery L_k. Let us call $L_{k''}$ the potential lotteries drawn from urn-2, then, obviously, $L_k \sim L_{k''}$.

By convention, $L_{\infty/\infty}$ represents the random choice of a lottery (i.e. playing randomly either urn-1 or urn-2). This is done by following a distribution of probability $(\beta, (1-\beta))$, where respectively, urn-1 is chosen according to probability β, $1 \geq \beta \geq 0$ and urn-2 with the probability $(1-\beta)$. Then, it follows that :

$$L_{\infty/\infty} = \beta L_{k"} + (1-\beta)(\gamma L_1 + (1-\gamma)L_k),$$

This expression takes into consideration both urns where one cannot cancel the impact of the information about the proportion of urn-1. If she considers the information accurate and if the lottery L_1 is favorable, then, for the first run, conforming to the information means that choosing urn $L_1 \succ L_k$, consequently, $\gamma L_1 \succ (1-\gamma)L_k$.

We establish proposition 1:

Proposition 1: *The condition for the DM to be confident in the information source and choosing in a non-random way is that:* $\gamma L_1 + (1-\gamma)L_k \succ L_{\infty/\infty}$ *or,* $L_1 \succ L_k$, $L_1 \succ L_{k"}$.

To prove it, consider that choosing urn-1 is preferred over choosing randomly if, as mentioned in proposition 1, i.e. :

$\gamma L_1 + (1-\gamma)L_k \succ L_{\infty/\infty}$ or $\gamma L_1 + (1-\gamma)L_k \succ \beta L_{k"} + (1-\beta)(\gamma L_1 + (1-\gamma)L_k)$

Consequently, by developing:

$$\gamma L_1 + (1-\gamma)L_k \succ L_{k"}$$

Then, as $L_k \sim L_{k"}$, $L_1 \succ L_k$, or $L_1 \succ L_{k"}$. This establishes the result in proposition 1.

The striking element is the fact that this result is free from any probability consideration. The DM chooses urn-1 because the information gives a proportion that reduces the uncertainty of the choice. This means that even if the source is weakly credible, the player prefers this to no information at all.

We can study the reverse case and wonder what may induce the DM to opt for a random choice. We show below, that, as she is a Savage expected utility maximizer, there is no room for operating this kind of choice. This is the object of the following proposition 2.

Proposition 2: *A Savage Expected Utility maximizer will always prefer not to play randomly because she always trust the information source, even if its reliability is weak.*

Proof:

1) We can consider that preferring playing randomly means that:

$L_{\infty/\infty} \succ \gamma L_1 + (1-\gamma)L_k$, or still:

$$\beta L_{k"} + (1-\beta)(\gamma L_1 + (1-\gamma)L_k) \succ \gamma L_1 + (1-\gamma)L_k$$

Proceeding to similar calculations, it happens that:

$L_{k"} \succ \gamma L_1 + (1-\gamma)L_k$ (a)

And, as $L_k \sim L_{k"}$, $L_k \succ L_1$. (b)

Then $L_{k"} \succ L_1$

This result says that the condition for playing randomly is considering that urn-2 is preferred to urn-1, this call attention on the motivations that lead to play randomly for the Savage DM.

Playing randomly, i.e. considering that $L_{\infty/\infty}$ is preferred to urn-1 comes to say that $L_{k''} \succ L_1$. Then, if the DM prefers $L_{k''}$ to L_1 as the condition for playing randomly, then, this is because she considers that $L_{k''}$ is preferred to all lotteries in urn-1 or still that :

$$\tilde{R}_2 > \gamma R_1 + (1-\gamma)\tilde{R}_1 = \tilde{R}_1 + \gamma(R_1 - \tilde{R}_1)$$

As by assumption, rejecting the information comes to consider that urn-1 and urn-2 are equivalent then, $\tilde{R}_2 > R_1$, consequently, as $\tilde{R}_2 = \tilde{R}_1$ (because otherwise, if $\tilde{R}_2 > \tilde{R}_1$it would have been better to not play randomly), $\tilde{R}_2 > R_1$. Indeed, as the information says that $R_1 - \tilde{R}_1 < 0$ and, even for a low γ, $\gamma > 0$, it follows the inequality.

Rejecting the information is like saying:

$$p(\tilde{R}_2) = p(\tilde{R}_1) \text{ and } (p(\tilde{R}_2), p\big(\tilde{R}_1\big) > p(R_1)).$$

It follows that, this last inequality induces the DM to choose urn-2 because otherwise, she runs the risk to meet urn-1 with R_1 that is less favorable than urn-2. Non-believing information is induced by the prior belief that urn-2 contains more red balls than urn-1. This belief can only be explained because it is a belief or still: Either you believe that the information is true, or you do not believe it.

To summarize our results: A Savage DM who decides to play randomly considers that $L_{k''} \succ L_1$ and/or $L_k \succ L_1$, this independently from any probability consideration about the source's reliability. Hence, an unconvinced DM about the given information will choose equivalently, L_k or $L_{k''}$. As for her $L_{k''} \succ L_1$, it would be absurd to play randomly, then, choosing L_k is better than $L_{k''}$ because first, she considers them equivalent and the information concerning urn-1 is better than urn-2.

2) In the opposite, a convinced DM about the information accuracy will choose urn-1, even for a low probability of the reliability of the source. To see the point it is sufficient to see the reverse of a) above. This establishes proposition 2.

$$\gamma L_1 + (1-\gamma)L_k \succ \beta L_{k''} + (1-\beta)(\gamma L_1 + (1-\gamma)L_k)$$

And after development: $L_1 \succ L_k$ or $L_1 \succ L_{k''}$ as $L_k \sim L_{k''}$. This result from the application of axioms 2 (Sure thing principle) and 3 (Independence).

Consequently, proposition 2 says that the choice for urn-1, after that the information is received is made independently from the level of reliability of information. Even if the credibility of the source receive a low probability, the DM will comply with it as shows it proposition 1.

3. Ambiguity theory applied to the information source

In what follows we analyze the behavior of agents that are not Savage Utility maximizers but behave more realistically.

3.1. The notion of capacity, neo-capacity, and Choquet utility functions.

As an extension of a probability, a capacity is a function $\tau(p)$ that assigns real numbers to events $\mathcal{E}$, where $\mathcal{E}$ is the set built from the set $\mathbb{S}$ of the states of nature. It fulfills two conditions. First, for all $E, F \in \mathcal{E}$, and $E \subseteq F$, then $\tau(E) \subseteq \tau(F)$ as monotonicity condition and second, as normalization conditions, $\tau(\emptyset) = 0$ and $\tau(\mathbb{S}) = 1$.

Capacities are integrated through Choquet integrals. This means that exists a simple function of finite range f such that it takes values $\mu_1 \geq \mu_2 \dots \geq \mu_n$. Then, a Choquet integral of a simple function f with respect to a capacity $\mu(.)$ is generically defined as:

$$V(f/\tau) = \sum_{\mu \in f(\mathbb{S})} \mu[\tau(\{s/f \geq \mu\}) - \tau(\{s/f > \mu\})] \quad [1]$$

Chateauneuf, Eichberger and Grant (2007) show that the Choquet integral overweight high outcomes if the capacity is concave or overweigh low income if the capacity is convex.

Let be $\mathcal{E}$ the finite set of states to which correspond the expected gain $\mathcal{A}$ (σ-algebra of $\mathcal{E}$). We consider a finite set of outcomes ($A \subset \mathbb{R}$) and let $\Phi = \{f: \mathcal{E} \to A\}$ be a set of simple functions from states to outcomes which correspond to simple acts and takes on values $a_1 \geq a_2 \dots \geq a_n$.

In the model the agents are gifted with a Choquet objective utility function. Their beliefs on the level of gain correspond to a neo-additive capacity (μ) based on (p). Hence, each category of agent will form beliefs about their expected payoff. The, we can define now the neo-additive capacity. To do that let us consider that the σ-algebra $\mathcal{A}$ is partitioned in three subsets that we present and characterize (for a more complete information see CFG (2002, 3).

- The set of null events $\mathcal{N}$, where $\emptyset \in \mathcal{N}$ and for $G \subset H$, and $G \in \mathcal{N}$ if $H \in \mathcal{N}$.
- The set of "universal events" $\mathcal{W}$, in which an event is certain to occur, (complement of each member of the set $\mathcal{N}$).
- The set of essential events, $\mathcal{A}^*$, in which events are neither impossible nor certain. This set is composed of the following:

$$\mathcal{A}^* = \mathcal{A} - (\,\mathcal{N} \cup \mathcal{W}) \qquad [2]$$

Before going further, we define the following capacities ν (see appendix):

$\nu_0(A) = 1$ if $A \in \mathcal{W}$ and 0 otherwise and $\nu_1(A) = 0$ for $A \in \mathcal{N}$ and $\nu_1(A) = 1$ otherwise.

Furthermore, we define a finite additive probability $p(.)$ such that $p(A) = 0$, if $A \in \mathcal{N}$ and 1 otherwise. To put it briefly, we consider now that psychological factors are leading in the decision process. Hence, let λ be the level of ambiguity preference with $\lambda = 1$ for an absolute preference for ambiguity and, the reverse $\lambda = 0$ and absolute aversion for ambiguity, generally, $0 \leq \lambda \leq 1$. Then, another weight is constituted by the level of optimism and pessimism. Let α be the level of optimism and $(1 - \alpha)$ the one of pessimism, with $(0 \leq \alpha \leq 1)$. Optimism applies to the maximum positive payoff, while pessimism to the opposite.

Definition 1: Let λ, α that belong to a simplex Δ in $\mathbb{R}^2$, $(\Delta := \{(\sigma, \rho) \,/\;\; \sigma \geq 0, \rho \geq 0, \sigma + \rho \leq 1\,\})$, a neo-additive capacity μ based on the distribution of probability $p(.)$ is defined as:

$$\mu(\,A\,/\;\,p, \lambda, \gamma) = \begin{cases} 0\; for\; A = \emptyset \\ \lambda\alpha\nu_0(A) + \lambda(1-\alpha)\nu_1(A) + (1-\lambda)p(A)\; for\; \emptyset \subsetneq A \subsetneq \mathcal{E} \\ 1\; for\; A = \mathcal{E} \end{cases} \qquad [3]$$

Then, a neo-additive capacity is additive on non-extreme outcomes. $(1 - \lambda)$ represents the degree of confidence of the agent in this belief. The Choquet integral based on neo-additive capacities is a weighted sum of the minimum, the maximum, and the expectation of a simple function $f\colon \mathcal{E} \to \mathbb{R}$ as the following relationship:

$$V(\,f\,/\,p, \lambda, \gamma) = \lambda\alpha\,.\sup(f) + \lambda(1-\alpha).\inf(f) + (1-\lambda)E_p(f) \qquad [4]$$

Where $E_p(f)$ is the expected payoff.

3.2. Ambiguity and the information source reliability

To deal with the problem, we consider that the game's first round is a super-lottery composed by the choice between L_1 and L_k, or $L_{k''}$ (the choice is indeed between urn-1 and playing randomly between urn-1 and urn-2 i.e. $L_{\infty/\infty}$. Let L_S be the representation of the choice between urn-1 associated to the information source revelation and $L_{\infty/\infty}$ between both urns. The probability distribution of L_S writes as:

$$L_S = \{L_1, \gamma;\; L_k, (1-\gamma)\,\}$$

It follows that the neo-capacity function drawn from these conditions writes as[4]

$$V_L = \;\alpha\,\lambda\,Sup\{L_1\} + (1-\alpha)\,\lambda\,Inf\{L_1\}\; + (1-\lambda)(\,\gamma L_1 + (1-\gamma)L_k) \qquad [5]$$

[4] Note that when discussing formally we keep the lottery notation, while by necessity we will refer to calculus, than we will use the expression in terms of ratio and probability.

We know that $Sup\{L_1\} = M$ and $Inf\{L_1\} = 0$, the above neo-capacity corresponding at the utility of drawing a red ball from urn-1 conforming to the information source writes:

$$V_L = \alpha \lambda M + +(1-\lambda)(\gamma L_1 + (1-\gamma)L_k) \qquad [6]$$

We can note by W_L the neo-capacity to play randomly, because the DM does not believe the information.

$$W_L = L_{\infty/\infty} = \beta L_{k''} + (1-\beta)(\gamma L_1 + (1-\gamma)L_k) \qquad [6']$$

Then, it becomes easy to study the conditions for which $V_L \succ L_{\infty/\infty}$ and the reverse. Then, after a simplification, where $\beta = 1/2$ (the DM plays randomly on the basis of a "head and tail" game) and $M = 1$.

$$V_L \succ W_L \Rightarrow \alpha \lambda + (1-\lambda)(\gamma L_1 + (1-\gamma)L_k) \succ \tfrac{1}{2} L_{k''} + \tfrac{1}{2}(\gamma L_1 + (1-\gamma)L_k) \quad [7]$$

And the reverse:

$$W_L \succ V_L \Rightarrow \alpha \lambda + (1-\lambda)\left(\tfrac{1}{2} L_{k''} + \tfrac{1}{2}(\gamma L_1 + (1-\gamma)L_k)\right) \succ \gamma L_1 + (1-\gamma)L_k \ [7']$$

Developing, [7] and [7'], considering that $L_k \sim L_k$, we get :

$$\alpha \lambda + \gamma\left(\tfrac{1}{2} - \lambda\right) L_1 + \left(\lambda\gamma - \tfrac{\gamma}{2} - \lambda\right) L_k \succ 0 \qquad [8]$$

$$\alpha \lambda - \gamma\left(\tfrac{1}{2} + \lambda\right) L_1 + \left(\tfrac{\gamma\lambda}{2} + \tfrac{\gamma}{2} - \lambda\right) L_k \succ 0 \qquad [8']$$

We can note that now, the information is really at stake and the probability about the reliability of the source does not vanish. [8] expresses the choice for urn-1 under uncertainty, while [8'] corresponds to the preference for a random choice. Both choices depend on the attitude facing ambiguity and the level of optimism and pessimism of the DM. It is easy to see that, now, the choice is not depending only on the conviction about the probability of a given color in a given urn, but of several factors.

We can easily note that in so far that the aversion for ambiguity is absolute ($\lambda = 0$), then, $L_1 \succ L_k$ for [7] and the reverse for [7']. This situation means that facing an absolute aversion to ambiguity we find again the Savage Utility situation.

We can, then establish the following proposition

Proposition 3: *Considering a situation described by [3], [4] and [5], where a neo-additive Choquet utility maximizer whose function is described either by [7] or by [7'], in the conditions of the game described in section 2.1, then taking account the information that urn-1 contains winning red balls in proportion* $\frac{R_1}{K} \geq 1/2$ *with a reliability of probability* γ*, then, if this probability is considered as weak:*

- *The DM who expresses preferences in [7] will choose in urn-1 in so far that $\alpha > R_k/K$. In the reverse case, she will play at random.*
- *The DM who expresses preferences in [7'] will choose to play randomly in so far that $\alpha > R_k/K$, and will choose urn-1*

Proof.

In the following, we consider that:

$$\lim \gamma \to 0$$

i) For instance, if the credibility of the source is quasi-null because of a low probability of reliability, ($\gamma \to 0$), the condition for playing urn-1 is then (considering [7]:

$$\alpha\,\lambda - \frac{1}{2}L_{k''} + \left(\frac{1}{2} - \lambda\right)L_k \succ 0$$

And, as by assumption, $L_{k''} = L_k$, then $\lambda(\alpha - L_k) \succ 0$, and considering the proportions of balls this means that $\left(\alpha > \frac{\tilde{R}_1}{K}, \text{ or } \alpha > \frac{\tilde{R}_2}{K}\right)$. Otherwise, choosing urn-1 in spite of a very weak level of confidence in the source, comes from the level of optimism that should be higher than the beliefs about the proportion of red ball in both urns. Note, that in this case, the degree of ambiguity λ vanishes.

ii) By the same argument, the condition for playing urn-2 is then (considering [7]:
$\alpha\,\lambda - \lambda\,L_k \succ 0$ or $\alpha \succ L_k$.

The argument is the reverse of the previous situation: In so far that the above inequality is respected, then the intention to play urn-2 prevails. But, if the degree of optimism is such that $\alpha < \frac{\tilde{R}_1}{K}$, then it is preferable to play urn-1 and conforming to the information. QED.

In conclusion, to the extent that the attitude toward ambiguity and the pessimism/optimism pair appear in the picture, the reliability of the source of information, while an important factor, is not the only one. The latter determines the choice for a given option. It is easy to see that choosing one urn depends on the relationships between $(\alpha, \lambda, \beta, \gamma)$. A given value may be compensated by the value of another variable, in such a way that choosing urn-1 when for instance the credibility of the source is high may be balanced by an opposite value in optimism/pessimism or a preference/aversion for ambiguity.

3.3. The DM believes in the information source but acts as if not.

For instance, let us consider [7] and let us study what should be the conditions for leading the DM to choose at random in spite in the fact that she believes the information. This means that now, the relation [7] writes as:

$\alpha\,\lambda + \gamma\left(\frac{1}{2}-\lambda\right)L_1 + \left(\lambda\gamma - \frac{\gamma}{2} - \lambda\right)L_k \preccurlyeq 0$ and developing and replacing the lotteries by the proportion of balls:

$$\left(\frac{\lambda}{\frac{1}{2}-\lambda}\right)\left(\frac{\alpha K - \tilde{R}_k}{R_1 - \tilde{R}_k}\right) \leq \gamma\,, k = 1{,}2$$

[9]

[9] is an interesting relationship. It shows that if it is verified, then the DM will resign playing urn-1 for a random choice. Note that all the following results necessitates that $\frac{\alpha K-\tilde{R}_k}{R_1-\tilde{R}_k} > 0\ (resp. \frac{\alpha K-\tilde{R}_k}{R_1-\tilde{R}_k} > 0$ Consequently when $(\alpha K - \tilde{R}_k) < 0$, (resp. $(\alpha K - \tilde{R}_k) < 0$) i.e. when the optimism level is sufficiently low such that $\alpha K < \tilde{R}_k$, (resp. $(\alpha K < \tilde{R}_k)$) then the required condition is that $R_1 < \tilde{R}_k$ (resp. $R_1 < \tilde{R}_k$). However, this is incompatible with the fact that the DM believes in the information. Then, here, the only valuable condition is that $R_1 - \tilde{R}_k > 0$. Consequently, if $\alpha K - \tilde{R}_k < 0$ (resp $\alpha K - \tilde{R}_k < 0$) the inequality is respected and then favors the random choice in so far that $\frac{1}{2} > \lambda$. In the opposite case, the value is the product of two negative values, and is positive, then the inequality should respect the fact that:

$$\left(\frac{\lambda}{\frac{1}{2}-\lambda}\right)\left(\frac{\alpha K-\tilde{R}_k}{R_1-\tilde{R}_k}\right) \leq \gamma \leq 1 \text{ i.e. } \left(\frac{\lambda}{\frac{1}{2}-\lambda}\right) \leq \frac{R_1-\tilde{R}_k}{\alpha K-\tilde{R}_k}$$

If this condition is not respected then, the value or the ratio will be $\left(\frac{\lambda}{\frac{1}{2}-\lambda}\right)\left(\frac{\alpha K-\tilde{R}_k}{R_1-\tilde{R}_k}\right) \geq \gamma \geq 0$ and, consequently the DM keeps on choosing the urn-1.

The same argument may be developed using [7'], where, after developing, the DM will choose to play randomly if:

$$2\left(\frac{\lambda}{1+\lambda}\right)\left(\frac{\tilde{R}_k - \alpha K}{\tilde{R}_k - R_1}\right) < \gamma$$

She will be induced to change her mind, (i.e. choosing urn-1) for

$$2\left(\frac{\lambda}{1+\lambda}\right)\left(\frac{\tilde{R}_k - \alpha K}{\tilde{R}_k - R_1}\right) > \gamma, k = 1{,}2$$

We remind that, [7'] assumes that $\tilde{R}_k - R_1 > 0$ and as $\left(\frac{\lambda}{1+\lambda}\right) > 0$, then, the necessary condition to respect the inequality is that $\tilde{R}_k - \alpha K > 0$ and $\tilde{R}_k - R_1$ close to 0 with $(\tilde{R}_k - R_1) < (\tilde{R}_k - \alpha K)$. We can immediately check that this is true if and only if $\left(\frac{R_1}{K}\right) > \alpha$. Hence, whatever the level of aversion of optimism, if $\left(\frac{R_1}{K}\right) > \alpha$, and $\left(\frac{\tilde{R}_k}{K}\right) > \alpha$ then, the DM will choose to play urn-1, even if she convinced that $\tilde{R}_k - R_1 > 0$.

As a partial conclusion, the above results show that believing that a given urn contains more winning balls than the other, is not a sufficient condition to induce the DM to choose this one. The degree of optimism and the aversion/preference for ambiguity are also leading factors.

4. Conclusion

Acquiring information is fundamental to reduce uncertainty but does not guarantee the ambiguity disappearance. Indeed, new information may increase uncertainty because of its nature or the reliability of its source. The purpose of this article was therefore to study the consequences of unreliable sources in the decision-making process when it is impossible to increase the level of knowledge or experience. To this end, we modified one aspect of one of Ellsberg's usual examples, namely the one with two urns and two colors. Specifically, we questioned the consistency of the information source regarding the proportion of balls in both urns. In the standard format, this information is regarded as reliable, whereas in our presentation this is no longer the case. Indeed, information can be the revealing factor of uncertainty aversion. For example, in the Ellsberg setting, knowing the proportion of balls in one of the boxes reveals the DM's attitude toward ambiguity.

The information source quality and the agents' beliefs are two fundamental factors that explain the DM's choices. These depends on the DMs' psychology and beliefs rather than on an "automatic" choice based on the consequence of a rigid pre-order of preference as in the Savage case. To emphasize this point, the paper distinguished between two types of agents that lead to different behaviors. First, it considered a Savage expected utility maximizer whose utility function depends on the fundamental Savage choice axioms. Second, it analyzed a DM's behavior whose expected choices depend on his level of ambiguity aversion and his degree of optimism. This corresponds to a Neo-Choquet Expected Utility maximizer. In our framework, the alternative is either to choose to follow the informant or to play at random considering that his voice is worthless. In contrast, a Savage expected utility maximizer is led to prefer to believe any information even if the credibility of the source is low rather than to play at random. This matter of fact is due to the weight of the axioms of independence and the "sure thing principle". Consequently, the alternative is only illusory and does not exist. Conversely, for a Neo-Choquet type expected utility maximizer, the possibility of preferring to play at random exists and depends on the factors mentioned above: the relationship to ambiguity on the one hand and, on the other, the level of optimism/pessimism.

This result may help to understand situations of total uncertainty when risks of serious harm (accident, illness, stress) may occur or when there is no clear explanation for a given phenomenon. Some agents will prefer not to believe the information source, and others will do it. However, as shows the Neo-Choquet Expected Utility case, the psychological motivations play an essential role in the DMs' final choice, the prior belief in the source relevancy may be balanced by the aversion for ambiguity and the degree of optimism.

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