Bounded rationality: psychology, economics and the financial crisis

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Abstract°

Classical mathematical algorithms often fail to identify in time when the international financial crises occur although, as the classical theory of choice would suggest, the economic agents are rational and the markets are or should be efficient and behave also rationally.

This contribution does not pretend to give a complete answer to these questions, but it will highlight some well-known limits of the classical theory of rational choice. In particular, the present paper will focus on the concept of bounded rationality. The work also makes some references to behavioral economics and to the literature of behavioral finance which has given important contributions in explaining the behavior and the anomalies of financial markets. Finally, following the approch of Simon, the paper proposes an analytical model to describe the behaviour of agents which are rationally bounded, risk averse and loss averse, emphasizing the relationship between psychology and economics which helps to explain the crisis in financial markets.

°Key words: Bounded rationality, rational choice, cognitive economics, behavioral finance, risk aversion.

JEL Classification: C60, B52, D81, D83.

Introduction[1]

The economic and financial crisis has created a climate of great uncertainty. People ask why speculation is constantly present in the markets and why individuals (at least some of them) are incapable of curbing speculative instincts to preserve the common good, the stability of the all system rather than the (hefty) gains of a few. Furthermore we wonder why the classical mathematical algorithms often fail to identify in time when the international financial crises occur if, as the classical theory of choice would suggest, the economic agents are rational and the markets are efficient and behave also rationally.

This contribution does not pretend to give a complete answer to these questions, but it highlights some well-known limits of the classical theory of rational choice and compare this theory of choice with the approach that seeks to combine economics and psychology and that has established itself as cognitive economics. In particular, the paper will focus on the concept of bounded rationality, which has in Herbert Simon its most influential theorist. The work also makes some references to the literature of behavioral finance which has given important contributions in explaining the behavior and the anomalies of financial markets. Finally, following the approch of Simon, the paper proposes an analytical model to describe the behaviour of agents which are rationally bounded, risk averse and loss averse. These agents are myopic in their behaviors, since they influence with their market sentiment the trend of financial markets causing losses at global level, while they are trying to protect themselves.

1. Economics and the 'perfect' rationality.

Economics in its classical conception is seen as a normative theory: how we should act. In its neo-positivist approach of systemic-formal nature, economics takes the form of nomologic - deductive propositions, which are obtained by reasoning, starting from unproven axioms. With these axioms we deduce the propositions of the theory, which requires the use of logic and mathematics. Thus economics presents itself as a rational science in the sense that its propositions are obtained by means of logic, in a way which is similar to rational mechanics. In economics, moreover, rationality is interpreted in terms of consistency not of substance. We have therefore a syntactic and non-semantic notion of rationality. The agents are rational if they have a coherent criterion of choice. The consistency of the choices implies that the agents are represented by a system of preference. Economics describes the choice as a rational process driven by a single cognitive process that includes the principles of the 'theory of rational choice' and it orders the decisions on the basis of their subjective expected utility.

In this view the "homo oeconomicus" appears perfectly rational and has a complete knowledge, while his economic choices, guided by rationality, are self contained in the economic sphere without affecting other aspects of the individual such as the emotions or being influenced by the environment[2].

[1] I wish to thank David Carfi and Mario Graziano for their helpful discussions and observations. The usual disclaimer here applies.

[2] Hogarth and Reder (1986) underline that the paradigm of rational choice provides economics with a unity that is lacking in psychology.

1.1 The rational choice theory.

Let's start analyzing the rational choice theory (RCT). The first basic parameter which is taken into consideration by the TRC is the 'preference'. The theory sets several basic axioms on the preference of a rational agent. The theory adopts a concept of rationality which can be represented in the following way:

Let **X** be a set of mutually exclusive alternatives. Economic agents are assumed to have preferences, denoted by $\succcurlyeq$, on this set **X**:
$x \succcurlyeq y$ means "x is at least as good as y".
The preference relation $\succcurlyeq$ is called rational if it satisfies the following two properties.
1. Completeness: For all $x, y \in \mathbf{X}$,
$x \succcurlyeq y$ or $y \succcurlyeq x$.
2. Transitivity: For all $x, y, z \in \mathbf{X}$,
$x \succcurlyeq y$ and $y \succcurlyeq z$ implies $x \succcurlyeq z$.

Thus, if an individual's preferences satisfy appropriate consistency conditions, then it is possible to associate a numerical value to each outcome through an utility function u (.).
By means of the utility functions it is possible to decline formally the principle of maximization.
The choice rule implied in the RCT is the following:
Let $\mathcal{B}$ be a family of non-empty subsets of **X** ("budget sets"). We call a correspondence

$$C : \mathcal{B} \to \mathbf{P}(X) : \mathbf{B} \to C(\mathbf{B})$$

a choice rule if, for any member **B** of the family $\mathcal{B}$, that is $\mathbf{B} \in \mathcal{B}$, we have

$$C(\mathbf{B}) \subseteq \mathbf{B} \text{ and } C(\mathbf{B}) \neq 0.$$

Then, $(\mathcal{B}, C(\cdot))$ is a choice structure.
Given $\succcurlyeq$, rational choice theory specifies the choice rule to be
$C^*(\mathbf{B}, \succcurlyeq) = \{x \in \mathbf{B} : x \succcurlyeq y \text{ for all } y \in \mathbf{B}\}$.
Thus the preference optimization implies that $C^*(\mathbf{B}, \succcurlyeq)$ picks the best elements in **B**;
under the assumption: $C^*(\mathbf{B}, \succcurlyeq)$ is non-empty for all **B**.
Agent behavior is preference-maximizing if $(\mathcal{B}, C(\cdot))$ fulfils the weak axiom of revealed preference (warp) (Samuelson, 1938,1948).

Let $\mathbf{B_1}, \mathbf{B_2} \in \mathcal{B}$ and $x, y \in \mathbf{B_1}, \mathbf{B_2}$. The choice structure $(\mathcal{B}, C(\cdot))$ satisfies the weak axiom of revealed preference if
$x \in C(\mathbf{B_1})$ and $y \in C(\mathbf{B_2}) \Rightarrow x \in C(\mathbf{B_2})$.

It can be shown that if
$(\mathcal{B}, C(\cdot))$ fulfils the weak axiom and $\mathcal{B}$ contains all subsets of **X** up to three elements, the choice rule $C(\cdot)$ can be rationalized uniquely by the preference-maximizing choice rule $C^*(\mathbf{B}, \succcurlyeq)$. This is achieved through choosing the preference ordering $\succcurlyeq$ such that
$x \succcurlyeq y$ if and only if there is a
$\mathbf{B} \in \mathcal{B}$ such that $x, y \in \mathbf{B}$ and $x \in C(\mathbf{B})$.

To apply this RCT it is not necessary to make any particular psychological assumption, but – as Hogart and Reder (1986) pointed out – the definition of rationality implied in this theory is broad and lacks specificity.

1.2 The expected utility theory

von Neumann and Morgenstern (1944) proposed an analysis of choice under uncertainty, which depends on strong assumptions of a psychological nature. The rationality is now represented by the maximization of the expected utility. The expected utility theory is nothing more than a criterion that facilitates choice under risk.

According to von Neumann and Morgenstern, individuals generally move in the reality following predetermined patterns of behavior, at the base of which there is the assumption that they always prefer to have a greater wealth than less. The theory studies the preferences underlying consumer behavior under risk, i.e. when the subject is asked to make a decision without knowing with certainty which *ex ante* state of the world will happen, but he knows the probability distribution, that is, it is known to him a list of possible events, each of which he associates a probability of occurrence. This theory assumes that each individual has stable and consistent preferences, and that he makes decisions based on the principle of maximization of subjective expected utility. So given a set of options and beliefs expressed in probabilistic terms, it is assumed that the individual maximizes the expected value of a utility function u (.). The individual uses probability estimates and utility values as elements of calculation to maximize his expected utility function. Thus he evaluates the relevant probabilities and utilities on the basis of his personal opinion but also using all relevant information available.

von Neumann and Morgenstern have proposed a well-known theorem in which they make the construction of an expected utility function possible. Any individual acting to maximize the expectation of a function u(.) will obey to four axioms, which are: completeness, transitivity, continuity, and independence[3]. The first two axioms (completeness and transitivity) have been explained in section 1.1. They require respectively that an individual has well defined preferences, which are therefore complete, and that preference is consistent across any three options, so the consistency requirement reminds us that intransitive preferences lead to irrational behavior.

The von Neumann-Morgenstern theorem is also based on a third axiom of continuity which states that the preferences of rational agents are ordered and without points of discontinuity. This axiom implies that for each P, Q, R $\in \mathfrak{l}$, if the lottery P is preferred to Q and Q to R , then exist $\alpha, \beta \in (0,1)$ such that you can construct a linear combination of P and R for which

$$\alpha P + (1-\alpha) R \succ Q \succ \beta P + (1-\beta) R$$

[3] The expected utility function can take three forms: is concave when describing the preferences of a risk averse individual; is convex type when describing the preferences of an individual willing to risk; is linear when describing the preferences of a risk-neutral individual. Thus an individual averse, neutral or risk lover has indifference curves convex, linear or concave. Thus, in the von Neumann-Morgenstern framework, we can define individual's attitudes towards risk without making any prior assumptions about his behavior.

The fourth axiom of independence is crucial, it assumes that a preference holds independently of the possibility of another outcome. For each P, Q, R $\in \mathfrak{l}$, if P $\succ$ Q $\succ$ R, and for each $\alpha \in (0,1)$

$$P \gtrsim Q \Leftrightarrow \alpha P + (1 - \alpha) R \gtrsim \alpha Q + (1 - \alpha) R$$

The expected utility theory has been generally accepted as a normative model of rational choice, defining which decisions are rational. If an individual does not maximize his expected utility he is designed to violate in his choices some precise axiomatic principles, which are rationally binding. This theory has also been applied as a descriptive model of economic behavior (Friedman, Savage, 1948; Arrow, 1971) so as to constitute an important reference model for economic theory. Finally, what emerges from the analysis of choice under uncertainty is the complexity of the system of choice.

2. Psychology into Economics. The cognitive dimension.

Within the scientific community there has been a growing need to consider adequately the complexity of economic phenomena and processes that guide the choices of the individuals.
During the fifties there have been important explorations along the boundaries between economics and psychology. In particular, experimental psychology, concerned with the study of actual behavior and aware of the complexity of choices, had highlighted the systematic (and unconscious) divergence of human behavior from the postulates of economic rationality. Then some economists using experimental results questioned the validity of the classical model of rational choice (Simon, 1959). Thus a new line of research, called behavioral economics, started to be developed, trying to relate psychological factors to economic behavior. One important contribution came from Herbert Simon's approach, that developed the notion of bounded rationality and the problem solving. Bounded rationality, in particular, depends – according to Simon (1972) – on the limits of attentive and computational capacity. Thus, he gave start to an approach based on the heuristics, that are interpreted as a trade-off between the limits of the human mind and the computing performance required by complex problems. Simon's concept of bounded rationality can be interpreted – according to Kahneman (2003) – as defining a realistic normative standard for an organism with a finite mind. Simon essentially criticized – on the basis of analysis conducted on the field – the lack of realism of the neoclassical economic theory based on the assumption of full rationality. Another major contribution came from the pioneering experimental studies of Allais (1953), which have given a boost to the cognitive economic approach. Allais' studies demonstrated that preferences of individuals violate expected utility theory, so he proved the systematic discrepancy between the predictions of traditional decision theory and actual behavior. The results of laboratory experiments conducted by Allais have shown that individuals chose inconsistently and that they preferred solutions which did not maximize the expected utility. In this way Allais have demonstrated that the axiomatic definition of rationality did not allow to describe and even predict economic decisions[4].

[4] Maurice Allais presented in Paris, in 1952, his famous paradox to an audience composed of the best economist of his generation; among others, Kenneth Arrow, Paul Samuelson, Milton Friedman, Jacob Marschak, Oskar Morgenstern and Leonard Savage.

Later, Ellsberg (1961) identified another paradox. He demonstrated another type of inconsistency in preferences, showing that individuals prefer to bet on a lottery with a chance of obtaining a win already known that on a lottery with ambiguous results. This aversion to uncertainty (ambiguity) of the individual is completely ignored in the expected utility model from a descriptive point of view, while is not considered acceptable from a normative point of view.

2.2. Bounded Rationality

In economics the concept of bounded rationality is associated to Herbert Simon (1955, 1956, 1957, 1972, 1979, 1991), who proposed the idea of bounded rationality as an alternative basis for the mathematical modeling of decision making. Simon has coined the term 'bounded rationality' in *Models of Man* (1957). In his view, rationality of individuals is limited by the information they have, the cognitive limitations of their minds, and the finite amount of time they have to make decisions. Bounded rationality expresses the idea of the practical impossibility (not of the logical impossibility) of exercise of perfect (or 'global') rationality (Simon, 1955). "Theories that incorporate constraints on the information-processing capacities of the actor may be called theories of bounded rationality" (Simon, 1972, p.162). Simon argues that most people are only partly rational while are emotional/irrational in the remaining part of their actions. He maintains that, although the classical theory with its assumptions of rationality is a powerful and useful tool, it fails to include some of the central problems of conflict and dynamics which economics has become more and more concerned with (Simon, 1959, p.255). Simon identifies a variety of ways to assume limits of rationality such as risk and uncertainty, incomplete information about alternatives, complexity (1972, pp.163-164). Furthermore, he asserts that an individual who wants to behave rationally must consider not only the objective environment, but also the subjective environment (cognitive limitations), thus you need to know something about the perceptual and cognitive process of this rational individual. Simon, therefore, considers the psychological theory very important to enrich the analysis for a description of the process of choice in economics. This is why he adopts the notion of procedural rationality, a concept developed within psychology (Simon, 1976), which depends on the process that generated it, so rationality is synonym of reasoning. According to Simon (1976, p.133), a search for procedural rationality is the search for computational efficiency, and a theory of procedural rationality is a theory of efficient computational procedures to find good solutions. Procedural rationality is a form of psychological rationality which constitutes the basic concept of Simon's behavioral theory (Novarese, Castellani, Di Giovinazzo, 2009; Barros, 2010, Graziano, Schilirò, 2011; Schilirò, 2011), in contrast to economic rationality, defined by Simon as 'substantive rationality'.

Another way to look at bounded rationality is that, because individuals lack the ability and resources to arrive at the optimal solution, they instead apply their rationality only after having greatly simplified the choices available. Actually, individuals face uncertainty about the future and costs in acquiring information in the present. These two factors limit the extent to which agents can make a fully rational decision. Thus, Simon claims, agents have only bounded rationality and are forced to make decisions not by 'maximization', but rather by *satisficing* , i.e. setting an aspiration level which, if achieved, they will be happy enough with, and if they don't, try to change either their aspiration level or their decision. *Satisficing* is the hypothesis that allows to the conception of diverse decision procedures and which permits rationality to operate in an open, not predetermined, space (Barros, 2010). Real-world decisions are made using fast heuristics, 'rules of thumb', that *satisfice* rather than maximize utility over the long run. Thus agents employ the use of heuristics to make decisions rather than a strict rigid rule of optimization. The agents do this because of the complexity of the situation, and their inability to process and compute the expected utility of every alternative action. In fact, there are limits in the attentive, mnemonic and computational capacity binding the computational load, hence the usefulness of automatic routines. Rationality is bounded by these internal constraints in the uncertain real world. Simon, therefore, relates the concept of bounded rationality to the complementary construct of procedural rationality, which is based on cognitive processes involving detailed empirical exploration and procedures ("search processes") that are translated in algorithms. This is in contrast to the notion of perfect rationality, that is based on substantive rationality, which derives choices from deductive reasoning and from a tight system of axioms, an idea of rationality that has grown up strictly within economics (Simon, 1976, 1997). For Simon "as economics becomes more and more involved in the study of uncertainty, more and more concerned with the complex actuality of business-decision making, the shift in program will become inevitable. Wider and wider areas of economics will replace the over-simplified assumptions of the situationally constrained omniscient decision-maker with a realistic (and psychological) characterization of the limits on Man's rationality, and the consequences of those limits for his economic behavior" (Simon, 1976, pp.147-148).

Simon, however, does not reject the neoclassical theory *tout court*, he describes a number of dimensions along which neoclassical models of perfect rationality can be made somewhat more realistic, while sticking within the vein of fairly rigorous formalization. These include: limiting what sorts of utility functions there might be, recognizing the costs of gathering and processing information, the possibility of having a "multi-valued" utility function.

Simon's work has been followed in the research on judgment and decision making, both in economics and psychology. Two major approaches produced important insights into perception mechanisms shaping the individual's internal representation of the problem: the ''heuristics and biases" program (Tversky, Kahneman, 1974), which has been fundamental to the contemporary development of behavioral economics[5]. The other approach, derived from Simon's work, is the ''fast and frugal heuristics" program (Gigenzer, Goldstein, 1996; Todd, Gigerenzer, 2003).

Tversky and Kahneman, in particular, offered a theoretical explanation about the observed deviations from perfect rationality, noting that people rely on " heuristic principles which reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations" (1974, p.1124). They explored the psychology of intuitive beliefs and choices and examined their bounded rationality (Kahneman, 2002, p.449). Tversky and Kahneman do not abandon the assumption that individuals are intelligent and intentional in making decisions, but they assume systematic and specific biases that move away the judgment from the perfect rationality of individuals. These authors highlighted that "failures" of perfect rationality depend on the specific ways in which people select and process the information mentally. Tversky and Kahneman (1979, 1984, 1986) articulated a direct challenge to the rationality assumption itself, based on experimental demonstrations in which preferences were affected predictably by the framing of decision problems,

[5] The literature on bias evidence is quite large. As stated by Conlisk (1996, p. 672) "the evidence suggests that the magnitude and nature of the errors are themselves systematically related to economic conditions such as delibaration cost, incentives, and experience. In this sense, investigation of bounded rationality is not a departure from economic reasoning, but a needed extension of it".

or by the procedure used to elicit preferences[6]. One major conclusion of this alternative approach is that the susceptibility of people to framing effects violates a fundamental assumption of invariance. Kahneman and Tversky (1979, 1984) also argued that any individual has a deformation of the probability, which is different between gains and losses and, moreover, the individual has aversion to losses. A loss, in fact, is more weighted by a psychological point of view than a gain.

Consequently taking into account framing effects, aspects like loss aversion, money illusion, etc. become relevant in strategic decision making, macroeconomic phenomena and financial decisions, so the model of choice based on perfect rationality with its underlying expected utility theory fails as an adequate descriptive model of choice under risk.

The other approach, derived from Simon's work, is the ''fast and frugal heuristics" program (Gigenzer, Goldstein, 1996; Todd, Gigerenzer, 2003). These fast heuristics are conscious processes, accessible to introspection in humans. Following Simon's notion of *satisficing*, Gigenzer and Goldstein have proposed a family of algorithms based on a simple psychological mechanism: one-reason decision making. These fast and frugal algorithms violate fundamental tenets of classical rationality: they neither look up nor integrate all information (Gigenzer, Goldstein, 1996). The heuristics are determined by a trade-off between the limits of the human mind and the computing performance required by complex problems. The psychology of choice is to codify these heuristics in humans, to help apply them in situations where they work well.

3. Behavioral Finance

The theory of expected utility is also applied to financial investment decisions. As in the RCT the agent is following a preference-maximizing choice, so financial decisions for the rational optimizing economic theory are based on the hypothesis that people calculate their rational advantage and then act consistently with that.

However, research in psychology have supported the view that emotional reactions to situations involving uncertainty or futurity often differ sharply from cognitive assessments of those situations, and that when such differences occur, it is often the emotional reactions that determine behavior. From the seventies onwards there has been an increasing interest towards psychological and sociological aspects in the analysis of financial behavior. Then there has been the development of a new branch of finance: the behavioral finance, which in itself combines aspects of cognitive psychology and financial theories in the strict sense. In practice this new approach seeks to explain the so-called financial market "anomalies" by analyzing the behavior of economic agents. The adoption of heuristics by individuals is necessary to solve the problems of everyday life, but in the financial sector it can lead to biases which have proved very expensive.

3.1 Behavioral finance: anomalies and biases.

In the reality of financial markets the fact that the price of a stock should coincide with its fundamental value seems to be more the exception than the rule. The "anomalies" in the behavior

[6] In their 'Prospect theory' Tversky and Kahneman have shown experimentally the presence of inconsistent judgments and choices by an individual facing the same problem presented in different frames ('invariance of failures'). It follows that the frame, or the context of choice, *coeteris paribus*, helps to determine a different behavior.

of prices and yields, in contrast to the hypothesis of efficient markets, are numerous and show that the securities are by no means in line with their fundamentals.

So there have been models which departured from economic rationality and form the idea of efficient markets. Usually these models do not abandon completely the rationality model as the basic framework, but they focus on some particular deviation that explains a family of anomalies.

In particular, the models of behavioral finance, used in the valuation of assets, usually criticize the efficient market theory based on the idea of "informational efficiency of markets", underpinned by Fama (1970), that a market is efficient in the sense of information if at all times the stock prices fully and correctly reflect all the available information. The theory of market efficiency has been challenged, for instance, by the discovery of some anomalies that would produce excess returns. De Bondt and Thaler (1985) have shown that bonds, characterized by particularly high yields (so-called winners), record in the aftermath the worst yield and vice versa. This depends on investors' overreaction to an event. Over the time the investors realize the error and correct their assessments causing a reversal of returns. Odean (1998), instead, have designed a stock market in which all traders believe they are above average. Bernatzi, Thaler (1995) represents in their model a stock market in which traders are myopic and loss-averse. Furthermore, Thaler and Shefrin (1981, 1988), who gave major contributions to behavioral finance, presented their behavioral life-cycle theory arguing that economists who wish to analyze the consumption-saving decision must address the bounded rationality and impatience of consumers. The behavioral-life cicle theory models consumers as responding to psychological limitations by adopting rules-of-thumb, such as mental accounts, that are used to constrain the decision making of the myopic agent.

Kahneman, Knetsch and Thaler (1991) analyzed the topic of loss aversion. They carried out a significant experiment based on the "endowment effect" where these authors demonstrated that the individuals feel a great sorrow when they loose the objects they possess, more than the pleasure would cause them to acquire those same objects, if they do not already possess them. So the "endowment effect" is an anomaly that causes a *statu quo bias* (a preference for the current state that biases the individual against both buying and selling his object). The "endowment effect" is connected to the particularly pervasive phenomenon of loss aversion, for which the disutility of a loss is greater than the utility of a win of the same size.

In the field of behavioral finance, the loss aversion appears to manifest itself in the investor behavior as an unwillingness to sell assets or other securities, if doing so forces the investor to achieve a nominal loss (Genesove and Mayer, 2001). This loss aversion helps to explain in particular why housing market prices do not adjust downwards during periods of low demand[7].

There is another approach, sympathetic to behavioral economics, which is neuroeconomics, a discipline at the turn of neuroscience and economics. This discipline aims at studying the processes underlying the decision-making choices and that reveals what instincts are activated when you have to do with the risk, the gains and losses. Neuroeconomics tries to offer a solution through an additional set of data obtained via a series of measurements of brain activity at the time of decisions. Neuroeconomic theory proposes to build brain-based models capable of predicting observed behavior (Brocas, Carrillo, 2010). The underlying idea of neuroeconomics is that the brain is a multi-system entity with restricted information and conflicting objectives characterized by bounds of rationality, so the decision-maker must be modeled as an organization. So the financial

[7] The literature of behavioral finance includes the lack of symmetry between decisions to acquire and maintain resources and the strong aversion to the loss of some (emotionally) valuable resources that could be completely lost.

models must take into account the neuro-cognitive constraints, i.e. the mechanisms put in place by the brain in response to certain environmental stimuli, and the influence of emotions on the choices of investment. This relatively new approach can be considered another development of Simon' s intuitions.

4. Bounded rationality and risk aversion: a model of financial behavior.

In this section I outline an analytical model which follows the approach of Simon regarding agents' bounded rationality and also takes into account behavioral concepts such as loss aversion (Bernatzi, Thaler, 1995; Kahneman, Knetsch and Thaler, 1991) and a strong aversion to risk. Loss aversion refers to the tendency of individuals to be more sensitive to reductions in their levels of well-being than to increases (Bernatzi, Thaler, 1995, p.73)[8]. In addition, an excessive perception of, and aversion to, risk on the part of investor is, in fact, the major source of current global economic problems. This aversion has resulted in an excessive desire for liquidity and relative safety. This behavior, which is partly rational, has brought to a situation in which the fear of risky investment has exceeded. This has led, in turn, a greater propensity to hold liquidity by the investors as they tried to protect themselves, but this behavior, pushed by psychological motivations, has caused losses at a global level.

4.1. Modelling bounded rationality.

We start from Simon's idea that an agent has constraints in his information-processing capacities. Since individuals are only partly rational, Simon (1972) assumes limits of rationality such as risk and uncertainty, incomplete information about alternatives, complexity.

A Decision-maker which should take some decisions at a certain time 0 is modeled by a pre-ordered space $(X, \leq)$:

- X is the set of all possible choices;

- $\leq$ is a binary relation everywhere defined on X which is (by assumption) reflexive, total and transitive.

We could generalize and direct this absolute-rational model of a decision maker in the following way:

1) the assumption that $\leq$ is everywhere defined is unrealistic: a decision maker is very often not able to define a preference on the totality of his strategy - set X;

2) the assumption of totality (according to which every strategy pair is comparable) is unrealistic even if the relation is not-everywhere defined;

3) the decision-maker very often should decide not just at a time 0, but during an entire time interval [0; T], in which the conditions of the market are changing in time.

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[8] This concept plays a central role in Kahneman and Tversky (1979) prospect theory.

In the first case, we remember that any strategy not comparable with no other strategy is a Pareto maximum, so that any such x is a possible choice of the decision maker.

In the second case, since a decision maker is erroneously supposing that his own preference is total, it is likely for him to obtain a violation of transitivity.

A way to overcome the third problem is to consider a family of preferences $(\leq_t)_{t \in [0;T]}$, any preference $\leq_t$ holds in charge at time t. We, at this point, could have different problems:

- the agent could erroneously think that any member $\leq_t$ of the family is preserving the preferences $\leq_{t'}$, with $t' < t$, and this is another form of bounded rationality;
- the agent could think he has one unique preference for the entire decision process;
- the agent could think that the family of preferences is continuous in some topological sense, so excluding dangerous "choice fractures" in the decision problems.

We consider a financial market modeled in a state preference context. In particular, we consider, for simplicity, a market with a unique financial asset. Moreover, firstly, we consider the classic case of financial model with *m*-possible states of the world, the same states, for any future time $t > 0$; for this reason we could identify the space S of any possible future state of the world with the set of the first *m* integers, which we shall denote by $\underline{m}$.

Assume the asset has an initial unit price p_0 (at time 0);

then, assume that at any future time *t*, the price $p(t)$ of the asset is a vector in $\mathbb{R}^m$:

the *i*-th component $p(t)_i$ of the vector $p(t)$ is the unit price of the asset, if the state of the world *i* has occurred.

So that the vector $p(t)$ is a random scalar (more precisely a random price).

Indeed, we could interpret our vector $p(t)$ as a function

$$p(t) : \underline{m} \rightarrow \mathbb{R}$$

associating to any possible state of the world *i* in $\underline{m}$ the possible price $p(t)(i)$

In this model, when we define a probability measure $\mu(t)$, at any time *t*, on the space S of all states of the world $\underline{m}$, we can evaluate the probability that a certain possible unit price could occur, at a certain time *t*.

Observe that a probability measure μ in this simple model can be assimilated to a positive unit *m*-vector with respect to the 1-norm (that is a positive *m*-vector μ such that $\sum \mu = 1$).

Note that an amplitude ψ (t) can be associated with any probability measure: the amplitude such that $\mu = \psi^2$, where $\psi^2 = \psi\psi$, is the component-wise product of ψ times itself.
If we consider discrete time, we could assume that the discrete dynamical probability amplitude

$$\psi : \mathbb{N} \rightarrow \mathbb{R}^m$$

follows an evolution law of the type:

$$\psi\ (t + 1) = U(t;\ t + 1)\ \psi(t);$$

for every t in ℕ where

$$\mathrm{U}(t;\ t + 1) : \mathbb{R}^m \to \mathbb{R}^m$$

is a unitary operator, for every time t.

A rationally bounded decision-maker could erroneously think that

$$\mathrm{U}(t;\ t + 1) = U(1);$$

for every time t.

4.2. Risk aversion, loss aversion and bounded rationality in financial choices

Another form of bounded rationality is related to the situation when every agent in a financial market is risk averse.

Instead of adopting a utility function that represents risk aversion, as, for exmple, the commonly used hyperbolic absolute risk-aversion function (HARA), we could represent risk aversion, of a certain agent, as a reaction function r : E → F sending any price p of a certain security into a decision $r(p)$ in ℝ indicating how much to buy (in algebraic sense) of that security, for example r could be defined by the function "integer" **int** as it follows:

$$r(p) = \mathbf{int}(p - p_0);$$

for every p belonging to a certain bounded neighborhood $U(p_0)$ of p_0 (and we could be interested only on this range $U(p_0)$).

But we have at least two problems:

- presumably, "usual" agents could have very similar reaction functions; especially agents of the same type;

- also banks have such reaction functions, the risk aversion of the banks brings to a situation of credit crunch.

Thus, the price p of a certain security is a reaction function to the actions of the agents on the markets, assume, for simplicity that p is a reaction function to the aggregate quantity of bought security and indicate by r the aggregate reaction of the agents, we have a kind of reaction chain (since we have a decision-form game $(r; p)$):

an initial price p_0 determines $r(p_0)$ which determines $p(r(p_0))$ and then

$$r(p(r(p_0)))$$

and so on ...

but also p is an order preserving function, so that both the values of price and bought security tend to the minimum possible level, leading to a crisis.

In other terms, we have a dynamical system tending to a state which determines the worst possible gain (or loss).

Conclusions

The financial crisis has raised many questions and created new problems for economic theory. It is not all certain that the mathematical algorithms devised by the classical theory can predict in time when the international financial crises occur, but, as this paper tried to argue, we can enrich our knowledge of the complex reality of financial markets through the fertile contribution of Simon and of behavioral economists.

Firstly, the present contribution has tried to argue that psychology and economics provide wide-ranging and relevant evidence that bounded rationality is important, so the notion as formulated by Herbert Simon represents a reference point for understanding economic behavior and economic processes. The work also underlined the relation between bounded rationality and procedural rationality which is the form of psychological rationality that constitutes the basic concept of Simon's behavioral theory. Moreover, the work examined the criticism to the classical theory of rational choice and to expected utility coming from behavioral economics. The analysis regarding the behavioral economics has highlighted failures of classical theory of rational choice, but also anomalies and biases in the behavior of the economic agents in financial markets, although the critical part of the behavioral theory seems more convincing than the positive and proactive part of the same theory, leaving a significant degree of indeterminacy in defining solutions. In the last section, this work also suggested an analytical model to describe the bounded rationality of the agents following Simon and that also takes into account loss aversion (Bernatzi, Thaler, 1995; Kahneman, Knetsch and Thaler, 1990) and a strong aversion to risk to demonstrate that the behavior of investors, influenced by psychological factors, leads to crisis and to losses at the global level.

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