Modelling an artificial stock market: When cognitive institutions influence market dynamics

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Modélisation d'un marché financier artificiel : les institutions cognitives comme facteur d'influence de la dynamique du marché.

Résumé

L'article propose une modélisation d'un marché financier artificiel construit pour s’interroger sur le processus de formation des prix et sur la dynamique de marché qui en résulte. La modélisation permet de mettre en évidence le rôle de l’information publiée sur le marché par les intermédiaires financiers que peuvent être les agences de notation ou les analystes financiers. Nous montrons que l’information publiée, et entendue comme Institution Cognitive, permet d’orienter les décisions d’investissement des investisseurs, qui sont des agents hétérogènes, dotés de capacités d’apprentissage et évoluant dans un environnement changeant. L’institution cognitive a une réelle capacité d’influence sur l’évolution du système et sur le mécanisme de formation des prix : elle favorise l’émergence d’une dynamique speculative du prix des titres en orientant les décisions d’investissement des agents dans une même direction. Finalement, nous montrons que les institutions en vigueur sur le marché orientent le résultat des interactions entre les investisseurs, qui composent le marché puisque l’information exogène diffusée par l’agence de notation est un point focal pour la décision d’investissement et participe à l’émergence d’une bulle financière.

Mots-clé : marché financier artificiel, investisseurs, institution cognitive, information, interaction, coordination, apprentissage, dynamique speculative.

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Abstract

The paper presents an artificial financial market designed to analyse market dynamics from the behaviour of investors. The model especially allows highlighting the role of a particular kind of institution in the orientation of market dynamics. The information – delivered by financial intermediaries as rating agencies and considered as a cognitive institution – directs the decisions of investors who are heterogeneous agents endowed with capabilities of learning in a changing environment. We demonstrate that the cognitive institution influences market dynamics as it allows the co-ordination of the decisions of investment in the same direction. The information delivered by rating agencies is clearly a « focal point » for investors and contributes to generate a speculative dynamic on the market.

Keywords: artificial model, financial market, investors, cognitive institution, information, interactions, co-ordination, learning, speculative dynamic.

JEL : B25, B52, C63, D83, D84, G12, G14
1. Introduction

Between 1990 and 2000, the American stock market has been characterized by a strong growth of firms’ capitalization and by the prevalence of a particular kind of shareholders in the capital of firms: the institutional investors. More generally, the United States have experienced, during this period, a growth without precedent marked by

\[\text{i) an important accumulation of capital (through the diffusion of ICT in particular), ii) high profitability profits, iii) the development of new kind of firms (capital venture, start-up) and iv) the strong increase of stock prices.}\]

This paper proposes to focus on a facet of this phase of growth, qualified of «New Economy », and particularly on the speculative dynamic of prices observed on the stock market. Is it possible to explain partly the emergence of a financial bubble by the investors’ behaviour?3

Our main purpose is to consider the emergence of a special dynamic of stock prices as the result of the way of reasoning of investors, in other words as the result of their strategies of investment.

On the one hand, this purpose calls for a particular definition of the market, the one that regards it as a complex system in permanent evolution, as a system whose product is explained by the numerous processes of interactions between its components. We refer to the works that consider economy as an evolving complex system (Arthur, Durlauf, Lane, 1997), as an adaptative nonlinear network (Holland, 1988). Indeed, these works put the emphasis on the system dynamic and on the interactions between agents composing a system.

On the other hand, this purpose led us to reject the fiction of the representative agent, however very much used in macroeconomics models (Malinvaud, 1995). These models are based on the assumption according to which the choices of an agent of a same category can be represented by the choices of a representative agent who maximizes a function of utility under constraints. The system dynamics is then considered as the result of the aggregation of the individual preferences in the figure of a particular agent: the representative agent (Kirman, 1992). This fiction, if it can be useful to carry out static analyses or analyses leading to situations of equilibrium is not adapted to our demonstration. We postulate that the stock market dynamics is not the result of the extrapolation of a standard individual behaviour but rather the consequence of the confrontation and evolution of the heterogeneous representations of investors (Kirman, 1992, 1998; Orléan, 1989, 1999; Tordjman, 1997).

To analyse the decisions of investors and their opinions about market dynamics, we propose an artificial model created thanks to the techniques of data-processing simulation. These techniques allow apprehending a global dynamic, such as the dynamic of stock prices,

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1 The artificial stock market presented in this paper has been elaborated in collaboration with Stéphane Sanchez who is a Ph-D student in informatics in the University of Toulouse, IRIT (Institut de Recherche d’Informatique de Toulouse), University Toulouse III, e-mail : sanchez@irit.fr
3 If we propose to explain the growth of stock prices by investors’ behaviours, we obviously recognize real factors that have participated to generate the financial bubble on the American stock market during the 1990’s.
4 This fiction is not well adapted to explain the opened market dynamics and is based on particular hypothesis (agents are notably endowed with a form of substantial rationality).
5 Our artificial market is built thanks to classifiers systems that are presented in the second paragraph and in appendix 1 of the paper.
as the result of the interactions between the decisions of the various investors composing the market. Indeed, simulation appears to be a particularly relevant tool when one seeks to analyse the emergence of a collective dynamic on a market, this dynamic being considered as the result of the interactions between individuals evolving in a complex environment (Ballot, Weisbuch, 2000).

It is more precisely a question of analysing behaviours of investment according to the nature of the informational signals provided to investors. We distinguish two kinds of information: an endogenous information, representing the information produced in the financial sphere and resulting from the interactions between investors on the market; an exogenous one, indicating for instance the information produced outside the market by financial intermediaries such as rating agencies or financial analysts. This distinction on the nature of information makes it possible to obtain results for two kinds of simulation: a first kind in which investors have only endogenous data, like the stock prices or the history of stock prices; a second kind in which investors have at their disposal a public information delivered by a rating agency, this information relating more precisely to the stocks prospects of growth.

We demonstrate that, in the first kind of simulation, investors manage to co-ordinate their decisions of investment around a stable state: the stock market quickly converges towards an equilibrium state. On the other hand, when investors dispose of an exogenous information, the market is not characterized any more by a state of equilibrium but on the contrary by a very strong volatility: there is emergence, then persistence of a financial bubble.

Finally, our artificial model highlights the power of a cognitive institution in the orientation of market dynamics and more precisely in the co-ordination of the decisions of investment of the various agents. By cognitive institution, one must consider « the institution which allows to polarize the anticipations formed by actors with different representations on their environment or their respective characteristics », (Walliser, 2000, p 185). We demonstrate that the cognitive institution – that is to say the exogenous information - has an undeniable role on the evolution of the system in the sense that this kind of information directs investors’ representations towards the same direction and generates a financial bubble on the market. From a theoretical point of view, we refer to the Old American Institutionnalist approach, and particularly to the works of Commons (1931) on the artificial selection; indeed, we consider the institution as a framework for the individual action. The cognitive institution directs the individual choices and supports the emergence of a particular dynamic on the market.

2. A justification of the artificial model

Our main objective consists in modelling the emergence of a collective dynamic on the stock market starting from an analysis of the investors decisions and knowing that investors are evolving in a changing environment. The purpose of neo-classic models is not to characterize the decision-making process of agents or to account for the many interactions that characterize investors. Those models rather question the efficient process of resources allowance under conditions of competition and scarcity: they are more centred on the analysis of the result than on the process of decision of agents evolving in a complex environment.

Data-processing simulation is mobilized as a complementary tool to these models since it does not lay down the same objectives and offers a different representation from the market. It is precisely interested in the decision-making process of agents in situations of uncertainty by considering that they do not make optimal decisions but adapt their decisions to the changes of the environment. Generally, one must consider that the technique of simulation is more appropriated than the traditional mathematical tools as soon as the market is not characterized by an equilibrium and an optimal state but rather by an alternation of phases, in other words as soon as it is a question of analysing a dynamic and an open system (Lane, 1993b).

Simulation makes it possible to understand how the components of a system interact to produce a complex dynamic and an emerging behaviour (Ballot, Weisbuch, 2000). On the one hand, it allows studying a global dynamic, in fact market dynamics, without providing an analytical representation of this dynamics. On the other hand, it allows accounting for the emergence of a global phenomenon and for the adaptation of investors to this emerging phenomenon. By emerging property, one must consider i) a property which can be described on a global level without referring to the specific attributes of the microeconomic entities composing the system; ii) a property which persists in the system; iii) a property which depends on the initial conditions of the system (Lane, 1993). We specify that the initial conditions of the artificial financial market define what is called a «state of the world» or a «model of the world».

One of the arguments often advanced in favour of a data-processing modelling of the market consists in supporting that this market is composed of many investors who take their decisions simultaneously and whose networks of interactions are too numerous to be studied in an analytical way (Tordjman, 1997). Indeed, analytical models are not adapted to account for the interactions between many individuals on a market or to predict the dynamic of an open system. Another justification in favour of simulation, undoubtedly more global, consists in supporting that this technique is adapted to any kind of analysis in which the environment of agents is complex in the sense that the information available exceeds the processing capacity of agents that compose the market (Moss, Rae, 1992). We consider that simulation is not sufficient to explain the emergence of behaviours or more generally an economic phenomenon. It must be apprehended like a heuristic to justify an emergent dynamic on the market, as a useful instrument to improve our analysis of the phenomena of «order » or « disorder » on a market (Lesourne, 1991).

The stock market that we present is built thanks to the tools that are classifiers systems. These systems are well adapted to the analysis of the emergence of a complex dynamic considered as the product of the interactions between heterogeneous agents composing the market. On a theoretical level, they are in keeping with the debate on the search for microeconomic bases to the macroeconomics since it is a question of explaining the emergence of a global phenomenon starting from the analysis of the individual behaviours and knowing that macroeconomic environment exerts an influence on the process of decision of agents. If we mobilize classifiers systems, it is especially because these tools allow analysing the process of decision-making in a complex environment. More precisely, they make it possible to apprehend the emergence of representations, here the emergence of rules.

7 « A complex economic system is one in which the information-processing capacities of agents are limited relative to the information available to them », p 25 in Moss, Rae, 1992.
8 See Goldberg (1971), p 236, for a detailed presentation of classifiers systems.
of investment, knowing that these representations are not fixed \textit{ex-ante} but result from the many processes of interaction between investors. One must note that each simulation carried out rests on initial conditions and provides a potential exploration of market dynamics\footnote{\textit{``each simulation giving the idea of a possible behaviour of the system''}, in Tordjman, 1997, p 878. One of the main limits of simulations rests on the fact that they are only valid for initial specific conditions which determine a \textit{``state of the world''} and therefore a particular history.}.

To resort to classifiers systems supposes to refer to a particular theoretical posture, the posture of the evolutionary research program and more generally the program called \textit{cognitive economy} (Walliser, 2000). This posture recognizes the importance of the cognition of agents to explain their behaviours and the resultant market dynamics. It is a question of considering that investors evolve in a changing environment, that they are endowed with representations on their environment as well as capabilities of learning. Their representations are not fixed \textit{ex-ante} but are emergent and change in the course of time thanks to the process of adjustment of investors to the evolution of their environment\footnote{It is precisely a characteristic of classifiers systems to exhibit properties of adaptation in a changing environment (see appendix 1).}. Finally financial markets are characterized by a succession of phases of \textit{order} and \textit{disorder}: the modelling is not referring to any static state but rather to a permanent process of adjustment in the system (Lesourne, 1991).

The posture of cognitive economy places in its centre the process of learning, process considered as the driving principle of the evolution of a system. This program particularly insists on the process of adjustment by which agents are able to face different situations as well as the process of learning according to which they manage to cumulate the past effects of the adaptive mechanism. We postulate that learning is primarily \textit{i) inductive} because investors observe the sequence of their last decisions of investment and try to find some regularities in stock prices dynamics to build a general law; \textit{ii) adaptive} because function of the past knowledge; \textit{iii) path-dependent} because resulting from the history of the interactions and finally \textit{iv) cumulative} because investors learn how to play again rules of investment which have procured them satisfaction in the past (David, 1985; Arthur, 1992; Tordjman, 1997). This conception of learning supposes that individuals have a memory to record their past results as well as criteria of judgment to select a rule of investment (Paulré, 1997).

The process of learning is characterized by an alternation of phases of tests and errors, phases during which each investor tries to select the \textit{``good''} rules of investment, in other words those which permit to generate an increase in portfolios value. The period of learning can be divided in two phases: a first phase of exploration during which investors try to discover the profits related to each rule of investment; a second phase of exploitation, during which they tend to play again the best actions, in other words actions which have generated an increase of profit (Walliser, 2000). The rationality of investors enables them to summarize the past profits and to create an index of profit for each activated rule, knowing that investors tend to reinforce decisions that have already generated profit\footnote{In conformity with the properties of classifiers systems.}. Investors’ preferences are thus expressed through an index that synthesizes their last experiments.

But which kind of rationality do we precisely mobilize to characterize investors? Their rationality is limited in the sense that each agent \textit{i) does not know the whole options that are offered to him} (informational limits); \textit{ii) is not able to evaluate all the consequences of his choices} (computational limits). Investors are not perfect calculators for they are neither able to solve a program of maximization, nor able to evaluate the effect of each one of their decisions.
in a complex and changing environment (Simon, 1979). This form of rationality could be interpreted as a form of weakened rationality compared to the completed rationality of the maximisator of utility, but we interpret it, on the contrary, as a form of completed rationality which recognizes the real limits in the means of choice of individuals in a situation of uncertainty (Mongin, 1984).

This form of rationality supposes the introduction of the concept of satisficing, this concept meaning that investors do not choose the best action in relation to the conditions of the decision but rather a satisfactory action whose evaluation have proved to be higher than the threshold of aspiration that they have initially fixed. The objective of investors is not to determine rules that would allow them to maximize their portfolios value but more simply to find a rule, which would increase this value. Finally, limited rationality supposes cognitive capacities less demanding than the program of maximization requires: to take their decisions, investors do not need nor to consider the whole scenarios, nor to determine an exact maximum value.

Investors are endowed with a situated rationality in the sense that they must adapt their choice to the concrete problem with which they are confronted (Walliser, 2000): it is a question of making a decision in a complex environment in order to increase the value of their portfolios. Their rationality is also situated in the sense that all take account of the resources of their environment to make their decisions: the environment procures them resources that facilitate their action (Orléan, 1994; Laville, 2000). Lastly, investors are characterized by a cognitive rationality because they must carry out the adequacy between the information they possess and their representations on their environment and on themselves (Lesourne, Orléan, Walliser, 2002).

3. Microstructure of the market

We propose to analyse market dynamics starting from the assumption according to which prices are the result of « the confrontation between the personal opinions of investors », (Orléan, 1999, p 32). Prices are not only the reflection of the fundamental value of the stocks but they integrate the representations of investors on market dynamics: they represent the average opinion of the investors’ community. In fact prices incorporate the average opinion of investors « to produce a judgment which has the statute of an evaluation of reference » (Orléan, 1999, p 32). Indeed, the average opinion is at the same time the result of individual representations and the object that is used as a basis for these beliefs (Orléan, 1989).

However, this approach does not mean that prices are only determined by the investors’ behaviours. It simply means that they take account of all the operators on the market and of their environment that continuously evolves. This approach especially permits to justify the formation of phases of turbulences on financial markets such as financial bubbles. The self-referential process that characterizes the decision of investment can largely explain these

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12 « one procedure (...) is to look for satisfactory choices instead of optimal ones », Simon, 1979, p 501.
13 Fundamental value means that the stock price corresponds to the actualised sum of future flow of earnings that the stock will generate during the exploitation of the firm.
14 Market dynamics is at the same time the result of individual actions of investment and a framework for individual actions in the sense that it influences investors’ representations.
15 Even if this hypothesis can be considered as accurate in the very short-term (Tordjman, 1997).
periods of disorder\textsuperscript{16}. Indeed, while trying to guess what will be the average opinion to beat the market, investors can lead prices to excessive levels in comparison with the real economic data. The price, which emerges on the market, imposes then not because it reveals the « true » value of the stock but rather because it reflects the majority opinion of investors (Orléan, 1999, p 57).

Lastly, the financial market must be apprehended as a system on which it is possible to observe phenomena of self-organization: indeed, a global structure, which did not exist at the start, can appear as the result of the many interactions between investors (Lesourne, 1991). The approach in term of self-organization more precisely design the capacity of a system to produce - in a way which is not necessarily voluntary or conscious - a structure, an organization, a behaviour and / or its own rules of functioning (Paulré, 1997, p 134).

Self-organization must be apprehended on two levels in the artificial model (Paulré, 1997). Initially, it indicates the capacity of the system to produce some rules of investment or a particular behaviour: there is emergence of a global order on the market. Then, this approach supposes that investors are able to adapt their behaviours of investment to their changing environment. One must insist on the mechanism of co-evolution between investors and their environment: on the one hand, the behaviours of investment which emerge on the market modify the environment; on the other hand, investors must adapt to the modifications of this environment. There is also a mechanism of co-evolution between investors in the sense that each investor transforms and structures the environment of the others.

Finally, the approach in term of self-organization supposes that the system builds its trajectory according to its experiment and according to the environment. Market dynamics is open\textsuperscript{17}, investors acquire information by observing the result of their interactions and they are able to adapt to a changing environment. One must note that the concept of self-organization, and by extension, the notion of emergence of a collective order, suppose on the one hand a vertical approach of the system since the order is explained starting from the microeconomic behaviours; in addition the two concepts underlie a causal dimension since the collective emergent phenomenon is thought as the consequence of the interactions between the individuals who compose the system (Paulré, 2000).

If we can observe elements of self-organization on the artificial market, it is because we have created an evolutionary model in which investors’ behaviours can potentially change because of their capabilities of learning. Let us present, now, the microstructure and the hypothesis of the financial artificial market.

3.1. Investors

The artificial market is composed of twenty investors who must take a decision in a situation of uncertainty at each period of simulation. Each investor can decide to purchase a stock, to conserve it, to sell it or to ignore it (in other words to do nothing).

Investors are heterogeneous agents for two main reasons. On the one hand, they manage portfolios composed of a variable amount of stocks and liquidities. In the model, liquidities always represent a random percentage of the amount of stocks and this percentage cannot

\textsuperscript{16} Stock prices are determined according to a « circular way »: investors take their decisions from prices in force on the market and prices are the result of their decisions of investment.

\textsuperscript{17} « open-ended dynamics », in Silverberg, 1988.
exceed, by convention, 100% of the total amount of stocks value. On the other hand, although investors have theoretically access to the same information, it is not sure that all will use it in an identical way to make their decisions. One must consider that information does not have an objective or an identical value for all investors and that the utility they withdraw from information depends on their cognitive capacities, in other words on their capabilities of processing this information.

Investors have an implicit objective through the system of payment for rules that we have created: it is an objective of gain in conformity with the postulate of «satisficing» and not an objective of maximization (Simon, 1979). Investors learn, starting from their past experiments, to modify their behaviours to increase their degree of satisfaction. Indeed, rules mobilized by investors are remunerated in a positive way - or «rewarded» - as soon as they generate an increase in the value of the portfolios and «penalized» when they lead to a reduction of this value. This system of payment and the functioning of classifiers systems make that the system is likely to generate an increase in the portfolios value, in other words to support the emergence of a speculative dynamic on the market.

Investors make their decisions under budgetary constraints, transactions of purchase being impossible when they do not have sufficient liquidities. In fact, no purchasing order will be effective if investors lack liquidities, constraint which can lead them to sell stocks in order to get liquidities to finally be able to buy new stocks.

Investors are endowed with capabilities of learning: at the beginning of each period, they make a decision of investment and analyse the result of their decision at the following period. At the start, all investors are unaware of the utility or more exactly of the profit associated with each rule of investment. So, they will successively test the various strategies of investment and by a process of inductive learning, will manage to discover how to readjust or play again rules according to the profits or losses incurred (Arthur, 1994)\(^\text{18}\). The object consists in selecting rules which get an advantage at one time in the system, in other words to retain only rules which can generate increases in the portfolios value.

Lastly, investors’ rationality can be described as limited and adaptive. Investors have limited cognitive and computational capabilities in the sense that \(i\) they are unable to test all the strategies of investment at their disposal in the system, \(ii\) they build procedural knowledge to take their decisions in a context of uncertainty\(^\text{19}\). If investors are not endowed with infinite and complete capabilities of calculation, they are however able to modify their decisions according to the evolution of their environment and so according to the behaviour of others. Their rationality is also \textit{situated} because investors take account of the global result of their interactions to make their decisions.

\textbf{3.2. The market}

The market is composed of twenty investors - modelled as classifiers systems - who must allocate the amount of their portfolios on ten firms with different characteristics. Firms are different by their stock exchange capitalization since the number of stocks and stock prices are different for each firm. Concerning the number of firms and stocks, it is important

\(^{18}\) « \textit{in situations that are complicated or ill-defined, humans use inductive methods of reasoning} », p 406 in Arthur, 1994.

\(^{19}\) At the beginning of each simulation, investors dispose of a pool of investment strategies, the set of conditions-actions defining 4000 potential rules of investment.
in the artificial model to specify that there is neither creation, nor destruction of firms and stocks for the 4000 periods during which simulations are carried out.

At the beginning of each simulation, the artificial market is created out of nothing with fictitious stock prices: prices and the allocation of portfolios on the various stocks are generated in a random manner.

We postulate that the financial market is « built » by investors in the sense that market dynamics is apprehended as the result of their interactions. The question is to recognize that the behaviour of others is important for the decision-making: investors are not isolated calculators, their choices of investment relate to the choices and behaviours of others. However, this method of evaluation which apprehends stock prices as the result of the decisions of investment does not mean for all that investors only decide according to stock prices, in other words according to the opinion of the others.

We propose to introduce an indicator to characterize each firm, indicator that can be compared to a classification of firms produced by a rating agency. This indicator, called *Expected Percentage of Growth (EPG)*, attests the possibilities of real growth of the firm: it is information on the « fundamental value » of the firm. The rating agency diffuses a grading of the ten firms according to this indicator knowing that the EPG indicator can take values ranging between less 10 % and more 10 % of the current price of the stock. Negative values of the EPG indicator mean unfavourable prospects of growth of stock prices contrary to positive values that testify favourable prospects. We specify that the values of the EPG indicator are given in a random way for each firm at the beginning of each simulation and that this signal reflects expectations of increase for stock prices for the following period. We make the assumption that the prospects for growth announced by the rating agency are correct, assumption that our system of payment for rules underlies (Appendix 2). Indeed, this system tends to support rules of investment that are in agreement with the prospects announced by the rating agency.

The advantage of such an indicator is to determine the influence that the EPG signal can exert on the investors’ representations and in fine on market dynamics. Do investors integrate or not the information provided by the rating agency to make their decisions of investment?

We create an institutional rule on the market, this rule having for vocation to avoid a tendency to disproportionate speculation. Thus, for their decisions of purchase, investors can propose a purchase price ranging between 0 and 10 % of the current price; concerning their decisions of sale, they can propose a price ranging between 0 and less than 10 % of the current price. This institutional rule makes it possible to validate the thesis of the organizing function of the market since we recognize that the institutional rules into force on the market are a framework for the individual action.

Lastly, we make the assumption that there are no transaction costs on this market and that information is free and accessible to all investors without discrimination.

**3.3. Informational signals on the market**

One of the important tasks relating to the model consists in specifying the information at the disposal of the various investors. By information at the disposal of an agent, we mean «any signal, any message, any perception which produces an effect on his behaviour or his cognitive state » (Melèse, 1979). We consider that investors receive two kinds of information
on the market: exogenous signals which indicate the information produced outside the financial sphere and endogenous signals which represent the information produced in the financial sphere by the actors of the market.

Exogenous signals are produced outside the financial market: they are represented in our model by the number of firms, the number of stocks on the market, the number of stocks that investors can purchase considering their liquidities, the stock prices at the beginning of each simulation and the rating of firms according to the EPG indicator.

Endogenous signals represent information that result from the confrontation of the investors’ opinions: those signals are information on the investors representations revealed through stock prices. Among these signals, one can find i) the current price of the different stocks; ii) the historical data for stock prices over the twenty last, ten last and two last periods; iii) the configuration of stocks at the preceding period: do stocks have a tendency to be purchased or to be sold? The historic data enables to postulate the existence of « chartists » behaviours as well as the role of memory in the decisions of investment: do investors hold account of the past data to make their decisions? Do they have a short term or a long-term memory? Concerning the configuration of the stock on the market, we postulate that each investor can take account of the others to make his decisions, in other words we introduce the possibility of mimetic behaviours of investment on the market.

3.4. Orders on the financial market: the role of the auctioneer

The aim is to present the way in which investors pass their orders on the market. On real financial markets, to pass a stock exchange order on a firm, it is important to know its notebook of orders. This notebook recapitulates, at one given moment, the state of supply and demand on a value to produce an equilibrium price, the price being determined so as to maximize the number of transactions on the market. We reproduce the operation of the notebook of orders before the opening of the Stock Exchange, which means that all investors make their decision in a simultaneous way and transmit their orders for each firm to the notebook or auctioneer. The auctioneer counts all the orders, eliminates « invalid » orders and treats the orders firm by firm in a random way.

A purchase order will be accepted if investors have sufficient liquidities at their disposal to be able to buy stocks and if they manage to find a counterpart. Concerning the order of treatment, a purchasing order will have priority on the other purchasing orders if it proposes the highest purchase price. Conversely, a sale order will have priority on the others if it proposes the weakest selling price. All orders cannot be carried out on the market, in particular when investors do not have sufficient liquidities at their disposal or when they do not find a counterpart. In conformity with the treatment of orders on real financial markets, orders are only valid on the day where they are emitted, in other words for only one period. So certain investors can be « rationed » over one period. But at the end of each period, all orders that are not carried out are withdrawn from the notebook of orders. Finally, at each period $T$, the notebook of orders is automatically given to zero (market clearing).

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20 A chartist investor tries to discover some regularities in the past data to predict the evolution of stock prices.
21 Sequential phenomena, like informational cascades, cannot occurred in our model.
22 Invalid orders are those which i) do not find a counterpart; ii) are transmitted to the auctioneer even though investors do not have sufficient liquidities at their disposal.
3.5. The unit of selection

The model includes two classifiers systems (Appendix 2). The first treats the purchasing orders: an investor can decide to buy or not to buy a stock (to ignore). The second treats their sale orders: an investor can decide to sell or to conserve a stock. At each period \( T \), classifiers systems receive a message of the environment and according to the conditions of the message they generate a particular action, which indicates a specific rule of investment. Therefore the unit of selection of our model is the rule of investment and not the investor.

To understand how the rules of investment are selected, one must specify the system of payment for rules. In \( t=0 \), in other words at the beginning of each simulation, the model is composed of 4000 rules of investment which have all the same weight, that is to say zero, and each rule can theoretically be mobilized with the same probability by investors. In \( t=1 \), the rule selected by each investor answers the conditions of the message and is chosen in a random way since several rules of investment can be activated to answer the same message. In \( t=2 \), by a process of induction, investors analyse the product of their decision and decide to play again or not the rule according to the profit obtained.

In fact, the system of payment is double: 1) a remuneration is related to the stock prices differences between two periods: do the value of the portfolio increase or decrease after purchasing or selling a particular stock? 2) a remuneration is related to the fact that investors take into account or not the information delivered on the market by the rating agency (Appendix 2).23

The process to learn the « good » rules is an inductive and a path-dependent process: in accordance with the functioning of classifiers systems, investors evaluate at each period the consequences of their decisions according to a simple procedure. They create a rule of «reinforcement » which supports the advantageous rules, in other words those that have already generate profit. When a rule is remunerated in a positive way, it sees its weight increased and is likely to be played again at the following periods: a rule will be all the more selected that its weight is high (Appendix 1).

Lastly, in our model, there is neither creation, nor destruction of rules but only adaptation of rules of investment mobilized by investors in a context of changing environment. Thus, it is not a purely evolutionary model creating a permanent variety of rules in the system, but rather a model of learning, investors being characterized by a process of continuous adjustment to their changing environment.

23 Our system of payment very lightly encourages investors to take care of the EPG signal delivered by the rating agency. For instance, decisions to purchase or to conserve stocks with a positive EPG value are remunerated in a positive way; decisions to sell or ignore stocks with a positive EPG value are remunerated in a negative way. But one must specify that it is mainly the first system of remuneration (the one without EPG) that determines the success of an investment rule.
4. Results

We present the results of two types of simulations whose purpose is to justify the emergence of a particular market dynamics starting from an analysis of the decisions of investors composing the market. The first type of results designs cases in which investors have only endogenous informational signals at their disposal to take their decisions; a second type is when they make their decisions starting from an exogenous informational signal delivered by the rating agency.

For each simulation carried out, we analyse market dynamics thanks to a stock index. This stock index makes it possible to evaluate the evolution of firms’ capitalization on the market, one of our purposes being in particular to evaluate the global performance of the market and the positioning of firms compared to this performance. We also propose a typology of investors according to their performances of management (do their portfolios value have increase or decrease?) and according to their strategies of investment (which rules of investment do they mobilize?). On the one hand, this typology give information on the determinants of the decision of investment; on the other hand, it permits to analyse investors performances compared to the value of the stock index: do investors reproduce the performances of the market, «under-perform» or «out-perform » the market?

Each simulation is carried out over 4000 periods and one period can be theoretically comparable at one day of pre-opening to the Stock Exchange.

4.1. Coordination of the decisions of investment: towards equilibrium

The first type of simulation is the one in which investors have only endogenous signals at their disposal to take a decision. In this first case, we find the results of the financial standard theory (theory of efficient markets) according to which the market converges towards a state of equilibrium. This state means in particular that prices contain all information available on the market: prices allow investors to make their decisions without having a perfect knowledge of the global functioning of the market. But how is it possible to justify this equilibrium, in other words this coordination of the decisions of investment in the same direction?

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24 The stock index is calculated from the aggregation of stock prices of the ten firms composing the market, knowing that prices result from the confrontation between the supply and demand of stocks on the market. The stock index value corresponds more precisely to the arithmetical mean of firms’ capitalization.

25 See Fama, 1970. The theory of efficient market stipulates that prices are sufficient to allow the co-ordination of the decisions of investment and to reach equilibrium.
4.1.1. Market dynamics: an equilibrium state

The analysis of the stock index reveals that it grows on average of $90\%$ on the whole period for all the simulations carried out\textsuperscript{26}. This progression is not continuous: indeed, the market always goes through a phase of strong growth (bubble), then through a decrease of firms’ capitalization (crash), to finally stabilize itself after the period of learning. More than to stabilize itself, the market balances between the period $t=2000$ and the period $t=3000$ for the whole simulations carried out. Investors manage to co-ordinate their behaviours without having an identical reference of equilibrium for all at the beginning of the «play», reference on which they could have a priori coordinated each other. Then how is it possible to justify such a co-ordination?

We cannot explain this co-ordination by the fact that investors have an identical idea of the equilibrium market price for there is no reference, no precedent, no convention at the beginning of each simulation (Schelling, 1986)\textsuperscript{27}. Therefore, we are led to propose an explanation starting from the process of learning that characterizes investors and the system of payment for rules. At the start, rules are mobilized in a random way by investors. Let us consider that the first emergent rules are remunerated in a positive way, these rules having generated an increase in the portfolios value. Our system of payment encourages investors to repeat decisions that generate profit and not to repeat decisions that lead to losses. In other words, if the first emergent rules lead to an increase in the portfolios value, these rules have a strong probability of being selected again, in accordance with the functioning of classifiers systems. Then the investor is likely not to explore the whole possible alternatives because of his limited computational capabilities. And if all investors behave in the same way, each one persisting in the exploitation of the first emergent rules that have generated profit, they can succeed in coordinating each other and prices finally stabilize after the period of learning.

\textsuperscript{26} The results are valid for the ten simulations realized with an endogenous source of information.

\textsuperscript{27} Schelling (1986) justifies the co-ordination between agents by the existence of a past unique solution called «focal point ».
«Because there are no fundamental variables and because only the actions of the others count, the place where the price stabilizes is random, it depends on the direction of the first “good” rules which emerge » (Tordjman, 1997, p 891).

Finally, the co-ordination of the decisions of investment towards equilibrium can be justified by the fact that investors persist in the exploitation of the first emergent rules and do not explore many alternatives (Holland, 1975)²⁸.

Concerning the horizon of management, our analyses reveal that investors take account of the historical record of stock prices to make their decisions. Generally, they take account of the trend of prices on the two last and the ten last periods to pass their orders. So, we cannot validate in a clear way one of the results often advanced on the short-term overview of investors: investors do not only take into account short-term data to make their decisions.

### 4.1.2. Typology of investors

In spite of the common characteristics to investors, namely the co-ordination of their decisions of investment around equilibrium and the taking into consideration of the historical data, a detailed analysis of their strategies of investment reveals three recurring kinds of behaviour of investment on the market.

**Type 1** includes investors whose performances of management are poor and negative, although these investors are those which manage at the start the largest portfolios²⁹. These investors have a very aggressive behaviour on the market: at the beginning, they practice an important policy of purchase until exhaustion of their liquidities, then they massively sell their stocks before managing to stabilize their portfolios at the end of the period. These investors buy whatever the configuration of the stock on the market and they tend to propose sale and purchase prices so that their orders are treated in priority. The rule of investment that generates the highest profit consists in purchasing a stock whatever its configuration. Finally, these investors are speculators without precise strategy with respect to prices, or with respect to the others. They behave as isolated calculators and only seek short-term profits by adopting very aggressive behaviours of investment: they continuously purchase and sale stocks.

²⁸ Holland (1975) underlines that the number of alternatives (here 4000 rules of investment) complicate the phase of exploration for the agents: individuals with limited capabilities are compelled to simplify the problem and will not explore the all set of alternatives. One can find this result in the model of Arthur (1997): the financial market finally reaches equilibrium because agents explore few alternatives.

²⁹ Negative performances correspond to a decrease in the value of the portfolios.
Type 2 includes investors whose performances of management are positive while remaining lower than the progression of the stock index. These investors are also speculators because they purchase and sale stocks in a very frequent way. But this group of investors differs from the first type by the adoption of specific principles of investment: they always purchase a small quantity of stocks and they sell stocks in a more massive way; they generally buy when the stock has a tendency to be sold – in other words when a potential offer exists on the market- and they sell whatever the configuration of the stock. These investors are strategic calculators in the sense that they learn how to split up their orders and they take account of the existence of an offer on the market to make their decisions. Thus, investors of type 2 do not behave as pure isolated calculators.

Type 3, finally, gathers investors whose performances of management are positive and much higher than the progression of the stock index. These investors manage to «out-perform » the average performance of the market. They purchase stocks when they have a
tendency to be sold at the preceding period, in other words when there is a potential offer, and they sell stocks whatever their configuration on the market. Contrary to investors belonging to type 2, they are characterized by behaviours of investment very targeted on certain firms, that is to say by a strong concentration of their portfolios on a reduced number of firms. So, their portfolios are not distributed in an identical way on all the stocks: one can speak about a targeted strategy. The rule that generates the highest profit for this group of investors is the one that consists in conserving stocks whatever their configuration on the market. These investors combine a short-term behaviour characterized by rapid movements of purchases and sales on certain firms, and a medium-term behaviour as their stable holdings on a targeted number of firms attest it. As the horizon of these investors is not only the short-term, we qualify them as «careful» investors: their targeted and stable holdings on certain firms probably means a form of aversion to risk.

This first type of simulation, in which investors have only endogenous signals at their disposal, enables us to find the stylised facts observed on real financial markets, namely i) aggressive investors behaving as isolated calculators and being not averse to risk; ii) investors taking account of the others (strategic calculators); iii) careful investors adopting complex strategies combining stable holdings on certain firms and frequent movement of purchases and sales on other firms.

However, this first type of simulation proposes results that are only valid for a particular market: the case of a market of pure speculation. Indeed, investors take their decisions from informational signals that are the product of their decisions of investment: there is not any information on the fundamental value or the «real» value of firms.

4.2. Exogenous information as a focal point for the co-ordination of the decisions of investment

The second type of simulation proposes a richer analysis of market dynamics because we introduce a new signal called Expectated Percentage of Growth (EPG). Investors have
from now on two kinds of informational signals at their disposal to make a decision: endogenous information and an exogenous one delivered on the market by a rating agency. In this last case, we demonstrate that the market is self-organized according to a more complex dynamic. Initially, the market is characterized by an alternation of phases of financial bubbles and crashes then by the persistence of a financial bubble. So, the market is characterized by a very strong volatility that we primarily justify by the presence of the cognitive institution represented by the exogenous information. Indeed, we show that this type of information is able to generate a speculative dynamic. But how does the EPG signal precisely operate on the criteria of investment of investors and on market dynamics?

4.2.1. Market dynamics or the emergence and the persistence of a financial bubble

Our analyses reveal that the stock index grows on average of 600% over the period for the whole simulations carried out30. The market dynamics is open-ended since it is characterized by a continuous growth of stock prices, in other words by a phase of financial bubble. Contrary to the first type of simulation, it is not possible to observe any stabilization of the financial market, no co-ordination of the decisions of investment on a particular point.

However, the progression of the stock index does not reflect the evolution of the capitalization of the various firms that compose the artificial market. Firms whose EPG value is negative or null (in other words firms that are badly classified by the rating agency) are those, which carry out the worst performances as regards the progression of their capitalization. Besides, investors have short-term holdings on these firms since their orders of purchase and sale are very frequent. On the other hand, firms whose EPG value is positive (in other words firms that are « well » classified by the rating agency) are those, which obtain the best performances. And the three firms with the strongest EPG value are those, which obtain higher performances than the progression of the stock index. Investors have medium-term or even long-term holdings on these firms.

30 The results are valid for the 10 simulations realized with endogenous information.
These results make it possible to advance the hypothesis according to which investors take stable and important holdings in firms with positive EPG value for they have discovered, after the period of learning, that the decision to invest in these firms was remunerated in a positive way. In a certain manner, investors adopt behaviours in conformity with the information delivered by the rating agency. These analyses, as for the impact of the EPG signal on the decisions of investment, are reinforced by the fact that investors who follow the recommendations of the rating agency, in other words investors who invest in firms with the strongest EPG value, are finally those who carry out the best performances of management.

These results, largely inductive, make it possible to highlight the role of « focal point » played by the EPG indicator: the information delivered by the rating agency has a real capacity on the orientation and on the evolution of the system by allowing the co-ordination of investors on certain firms and by generating a speculative dynamic on the market. But how is it possible to justify this mechanism of co-ordination?

The mechanism is simple: to make their decisions, investors formed representations which they successively test. They also have the EPG signal at their disposal to forge expectations on the prospects of growth of the stocks. If all investors take account of the EPG signal31, they will all decide to invest in the « recommended » firms in other words in firms with positive EPG value. This behaviour will mechanically cause an increase of the stock price since the supply of stocks becomes higher to the demand. Carrying out profits on firms with a strong EPG value thanks to obtaining plus-values, the rule of investment will be remunerated in a positive way and considered as a « good » rule. So investors will continue to mobilize this rule by a process of self-reinforcement and this behaviour will generate a new increase of stock prices. Finally, there is a self-realization of the prospects of growth announced by the rating agency in the sense that, investors, while following the exogenous information and while investing in the «recommended» firms, generate an increase of the firms’ capitalization. The market dynamics that results from this mechanism of learning by «self-reinforcement » of the good rules is not characterized by a co-ordination of investors on equilibrium but by a dynamic of financial bubble.

4.2.2. Typology of investors

The analysis of the rules selected by investors reveals again three recurring kinds of behaviour of investment.

Type 1 includes, like previously, investors who manage at the start the largest portfolios and whose performances are however weak and negative. These investors speculate in an important way on all stocks and do not have any stable holdings. We cannot advance any particular factor to determine their strategy of investment: these investors take account neither of the configuration of the stocks, neither of the trend of stock prices, nor of the EPG indicator. Concerning the EPG, one can even note a very small tendency to buy stocks whose EPG value is negative or null, but in a general way, the EPG is not a determining factor for the decision of investment. Finally, these investors are short-sighted speculators behaving as isolated calculators, without any directing principle relating to the decision of investment. Their orders are massive and frequent on all stocks.

31 We precise that our system of payment for rules lightly encourage investors to take care of the EPG information (see appendix 2).
Type 2 includes investors whose performances of management are positive while remaining lower than the progression of the stock index. Contrary to the preceding group of investors, it is possible to highlight particular criteria of investment. First, the EPG indicator is a determining factor: investors have stable holdings in firms with positive EPG value and they speculate in a permanent way in firms whose EPG value is negative or null. At the start, investors adopt a short-term strategy; after the period of learning, they adopt a medium-term behaviour on firms recommended by the rating agency. At the end of each simulation, the rule of investment that generates the highest profit is the one that consists in conserving stocks whose EPG value is positive. Globally, these investors purchase stocks when they have a tendency to be sold and they sell stocks when they have a tendency to be purchased at the preceding period. So their behaviours depend on the existence of a potential offer on the market at the previous period. Finally, these investors do not behave as isolated calculators but take into account the other agents and have stable holdings on firms recommended by the rating agency.
Lastly, type 3 includes investors whose portfolios growth is higher than the one of the stock index. For this group of investors, the EPG indicator is a determining factor for the decision of investment. Globally, these investors have very stable holdings -and even quasi-monopoly behaviours- in firms with positive EPG value and a very aggressive behaviour on firms with negative or null EPG value. In other words, these investors adopt a medium-term strategy on firms recommended by the rating agency and an aggressive behaviour on firms with the worse prospects of growth. In a very clear way and concerning their decision of investment on firms with negative EPG value, these investors purchase stocks when their price increase, sell stocks when they drop and conserve stocks when their price are stable (in accordance with the principle of the «destabilizing speculation», De Long, Shleifer, Summers, Waldmann, 1990). Generally, this group of investors learn to propose a very high purchase price - near to 10 % of the current price - so that their orders are treated in a priority way. Lastly, the rule that generates the highest profit at the end of the period of learning is the decision to conserve stocks whose EPG value is positive. Finally, investors of type 3 manage to out-perform the market by adopting a complex strategy: i) they take into account of the other agents through the recognition of a potential offer on the market; ii) they consider the information delivered by the rating agency to decide to invest in such or such firm; iii) they adopt a careful strategy which consists in conserving stocks whose EPG value is positive, in other words stocks «recommended» by the rating agency.

5. Concluding remarks

The main interest of this model is to register market dynamics from the point of view of cognitive economics, approach which grants a central role to the investors’ representations and to their processes of interactions. It is a question of analysing their way of reasoning in a situation of uncertainty through the formation of their representations, symbolized by the rules of investment. The purpose is especially to explain the emergence of a global dynamic on the financial market starting from the interactions of dispersed investors who are endowed with capabilities of learning. Investors are able to adapt to the evolution of their environment that evolves under the effect of their own decisions of investment.
The model allows predicting several elements as for the potential dynamic of the market and makes it possible to find stylised facts of financial markets.

First, the model enables us to reject the fiction of the representative agent, designed like an isolated calculator maximizing its utility function under constraints (A.P. Kirman, 1992, 1999). On the contrary, we consider that investors are heterogeneous agents, dispersed on the market, acting in parallel and taking account of the others (in other words of the collective opinion) to form their decisions of investment (Arthur, Durlauf, Lane, 1997). Market dynamics is largely based on a special evaluation of stock prices according to which price are the product of the interactions between investors, the result of their opinions (J.M. Keynes, 1936; A. Orléan, 1999).

The model also brings lightings on the question of the co-ordination of the decisions of heterogeneous and decentralized agents. Indeed, it allows to answer partly an old question: how an economic order can emerge starting from the interactions of investors motivated by the search for their personal interests - here the increase of their portfolios value? - We demonstrate that when investors have only endogenous informational signals at their disposal, which are the result of their interactions, they succeed in co-ordinating each other on a stable equilibrium. This result is all the more surprising that there is nor precedent nor common reference enabling them to co-ordinate quickly (T.C. Schelling, 1980). We primarily explained this result by the process of learning and by the system of payment for rules: the first emergent rules, if they generate an increase in the portfolios value, and therefore profit, will be remunerated in a positive way. The functioning of classifiers systems makes that these rules will be mechanically played again. And, if all investors act in the same way, in other words if all decide to play again the first emergent rules, the system is likely to converge towards an inert state (H. Tordjman, 1997).

The artificial model especially makes it possible to highlight the power of a cognitive institution - here the information delivered by the rating agency and represented by the EPG signal - in the orientation of market dynamics. This information has the power to direct investors’ representations in the same direction. The rating agency has a real capacity of influence since it contributes to generate a strongly speculative dynamics. Indeed, when they take into account the EPG indicator and invest in firms «recommended » by the rating agency, investors cause mechanically, by their decisions of investment, a rise of the stock prices: there is a self-realization of the prospects of growth announced by the agency.

Finally, the artificial model enables us to postulate that cognitive institutions, represented here by the exogenous information at the financial market, have a real capacity of influence on the evolution of the system. They are more precisely a factor which can generate instability on the market, market dynamics being characterized by an alternation of phases of order and disorder, in other words by a strong volatility. However, our purpose is not to deliver a judgment on the function or on the utility of rating agencies on the market. It is rather to underline the influence that a particular type of information, and thus a particular type of institution, can exert on the representations of investors and on market dynamics.

In a sense, the model pleads for a recognition of the public regulation since we demonstrate that institutions in force on the market have a real capacity to act on the
representations of the agents (in inciting them by an inflow of information) and thus on market dynamics\(^{32}\).

**Bibliography**


\(^{32}\) The model only presents preliminary results. A perspective of the model could consist in modifying the classification proposed by the rating agency to measure the effect of this informational shock on the investors’ behaviours and on market dynamics.


Appendix 1: Note on classifiers systems
(from the paper of Marengo, Tordjman, 1996)

1. Definition

The definition of classifiers systems to which we refer is the one of D.E. Goldberg (1991): «a classifier system is an automatic system of learning which learns simple rules in the form of chains (classifiers) which guide its behaviour in an arbitrary environment. This system is composed of a system of rules and message, of a system of distribution of the credits and of a genetic algorithm ».

Genetic algorithms are based on the mechanisms of natural selection and on genetics. They use the principles of the survival of the best-adapted structures. They were created by J. Holland (1975) i) to explain the process of adjustment of natural systems; ii) to conceive artificial systems that have the properties of natural systems.

2. The rules

Agents are modelled as classifiers systems: they can be characterized by a set of rules of the form: condition (if) - action (then). A rule (or an action) is activated for a particular condition (or a « state of the world »).

\[ R_i = \{ R_1, R_2, \ldots, R_q \} \text{ where } R_i = (c_1, c_2, \ldots, C_n) \rightarrow (a_1, a_2, \ldots, a_p) \]

To each condition \( c_i \) with \( i = 1, \ldots, n \) corresponds an action \( a_i \) with \( i = 1, \ldots, p \).

\( C = (c_1, c_2, \ldots, c_n) \) indicates the set of possible conditions and \( c_i = \{1, 0, \#\} \). The state of the world is defined by the set of conditions which are realized (1), are not realized (0) or do not have importance (\#).

\( A = (a_1, a_2, \ldots, a_p) \) designs the set of actions, \( a_i = \{0, 1\} \) and \( p \) represents the number of possible actions. Element 0 means « do not start the action », element 1 means « start the action ».

At the beginning of each simulation, individuals are supposed to be ignorant about the characteristics of the environment: rules are generated in a random way. So, the value of a particular rule is not fixed ex-ante: it is information that is learned during simulations.

3. Treatment of rules

Message of the environment: a signal is received from the environment and reaches the classifier system. This signal specifies a state of the world and the agent has to choose an action that corresponds to this particular model of the world.

Competition between rules: several rules whose conditions are satisfied compete to design which rule will finally execute the action. Rules enter in competition according to their force and specificity. The force (or weight) of a rule measures the effectiveness or the utility of the rule in the past. The utility of a rule is measured by the cumulated payment for the rule in other words by the payoffs cumulated every time the rule is applied. The specificity of a rule measures the precision of the condition, in other words its relevance to the present situation.
To enter the competition, each rule proposes an offer (called «bid»), which depends on its weight and its specificity:

\[ \text{Bid (} R_{it} \text{)} = k_1 (k_2 + k_3 \text{ Specificity (} R_i \text{)}) \times \text{Weight (} R_{it} \text{)} \]

where \( k_1, k_2 \) and \( k_3 \) are constant coefficients. The rule is selected in a random way proportionally to these bids.

**Action and actualisation of the weights**: the rule, which gains competition executes the action. This rule sees its force reduced by the amount of the bid and increased by the payment, which the action receives.

### 4. Selection and evolution of the rules

Two genetic algorithms respectively manage the competition between the existing rules and the evolution of the rules.

The «bucket brigad algorithm» (J Holland, 1975): this algorithm manages the competition between the existing rules by redistributing the profit carried out by the system with the rules, which generated the most profit. The force of a rule, which generated profit, will increase. The stronger the rule is, the more its probability of being selected at the following period is high. This first algorithm ensures the selection of the existing rules, which carry out the best performances: it is about a mechanism of learning by exploitation of the best rules.

A second algorithm recombines segments of existing rules to create new rules. New rules are supposed to replace the least powerful knowing that the number of rules in the system must remain constant. New rules will remain in the system only if they acquire a force by the mechanism of the first algorithm. The search for a new rule is not random but guided by the history of the system or the interactions since the object is to discover -in the existing rules-elements, which explain the success of these rules in order to better exploit them. By application of genetic operators (specification, generalization and crossover), it is possible to recombine the most effective rules to create new rules in order to improve the performance of the system.

### Appendix 2: Payment for rules on the artificial stock market

For each period \( i \) of the simulation and for each firm, we consider the following data:

- \( p_{i1} \): for period \( i \), the price of the stock at the time \( t_1 \), before the realization of the transaction (that is to say stock price at the time of the decision-making)

- \( p_{i2} \): over the period \( i \), the price of the stock at the time \( t_2 \), after the realization of the transaction (that is to say the new emergent price on the market)

- \( G_i \): payment for the rule involved in the decision of investment for period \( t_i \)

- \( G_{ij} \): payment for the rule of investment from period \( t_i \) to period \( t_j \)

- \( N_{bSf} \): number of stocks of the firm

- \( N_{bSpi} \): number of stocks purchased at period \( t_i \)
N_{bSOi}: number of stocks owned at period t_i

N_{bSsi}: number of stocks sold at period t_i

1. Payment for rules of investment in the first type of simulations: simulations carried out without the EPG signal (with only endogenous information)

For this first type of simulation, rules of investment are remunerated according to the increases or decreases in the portfolios value: does the rule selected by an investor generate gains or losses?

1.1. Payment for the classifier PURCHASE / IGNORE

Decision to ignore:

\[ G_i = -1 \times (p_{i2} - p_{i1}) \times N_{bSf} \]

Decision to purchase:

The rule that generates a purchasing order is never remunerated at the moment of the transaction (in other words at period t_i) for when one investor purchases a stock, he only transforms his liquidities into stocks. The rule is remunerated by the profits or losses that the acquired stocks permit to generate from the moment of the purchase. In fact, the rule is remunerated as long as investors conserve their stock.

So if p_i indicates the period when the investor purchases stocks of a particular firm and if p_j indicates the current period, the payment for the rule will be:

\[ G_j = \sum_{k=v+1}^{j} (p_{k2} - p_{k1}) \times N_{bSo_k} + \sum_{k=v+1}^{j} (p_{k2} - p_{k1}) \times N_{bSs_k} \]

1.2. Payment for the classifier SELL / CONSERVE

Decision to sell:

\[ G_i = (p_{i2} - p_{i1}) \times N_{bSs_i} \]

Decision to conserve:

\[ G_i = (p_{i2} - p_{i1}) \times N_{bSo_i} \]
2. Payment for rules of investment in the second type of simulations: simulations carried out with the EPG indicator (endogenous and exogenous information)

For this second type of simulation, the payment for a rule of investment depends on the i) expectations on new stock prices considering the EPG information; ii) on the gains or losses that this rule generates.

2.1. Payment for the classifier PURCHASE / IGNORE

Decision to ignore:

\[ G_i = -1 \times (p_{i2} - p_{i1}) \times NbSf - p_{i1} \times EPG_i \times NbSf \]

Decision to purchase: at the moment of transaction \( p_t \), the rule which generates a purchasing order is remunerated only according to the EPG indicator: do investors take account of this exogenous information to make their decisions of investment? In other words do investors follow the predictions of the rating agency? Then the rule is remunerated according to the profits or losses that the acquired stocks permit to generate for the portfolios value.

\[ G_y = p_{i1} \times EPG_i \times NbSp_i + \sum_{k=t+1}^{n} ((p_{k2} - p_{k1}) \times NbSo_k + p_{k1} \times EPG_k \times NbSo_k) + \sum_{k=t+1}^{n} (p_{k2} - p_{k1}) \times NbSs_k \]

2.2. Payment for the classifier SELL / CONSERVE

Decision to sell:

\[ G_j = (p_{j2} - p_{j1}) \times NbSs_j - p_{j1} \times EPG_j \times NbSs_j \]

Decision to conserve:

\[ G_j = (p_{j2} - p_{j1}) \times NbSo_j + p_{j1} \times EPG_j \times NbSo_j \]
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