Nonlinear Analysis: Real World Applications 12 (2011) 1235–1242

Contents lists available at ScienceDirect

Nonlinear Analysis: Real World Applications

journal homepage: www.elsevier.com/locate/nonrwa

Information-based multi-assets artificial stock market with heterogeneous agents

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A R T I C L E I N F O

Article history:
Received 22 December 2009
Accepted 24 September 2010

Keywords:
Artificial financial markets
Multi-assets
Information graphs
Random matrix theory
Static and dynamic factors

A B S T R A C T

In this paper, an artificial stock market characterized by heterogeneous and informed agents is presented. The heterogeneous agents are seen as nodes of sparsely connected graphs. The agents trade risky assets and are characterized by sentiments, amount of cash and stocks owned. Agents share information and sentiments by means of interactions determined by graphs. A central market maker (clearing house mechanism) determines the price processes for each stock at the intersection of the demand and supply curves. In this framework, the statistical properties of the univariate and multivariate process of prices and returns are studied. Importantly, concerning univariate price processes, the proposed model is able to reproduce unit root, volatility cluster and fat tails of returns. The multivariate price process exhibits both static and dynamic stylized facts, in particular the presence of static factors and common trends. Static factors are studied making reference to the cross-correlation between returns of different stocks, whereas the common trends are investigated considering the variance–covariance matrix of prices. The proposed approach allows to endogenously reproduce the multivariate stylized facts.

0. Introduction

The increasing interest towards complex systems characterized by a large number of simple interacting units has led to the development of co-operations in the fields of engineering, physics, mathematics and economics [1–4]. The availability of a large financial data set has allowed to deepen the knowledge about price formation processes and *stylized facts*. Fat tails, the lack of correlation of returns, long range positive correlation of volatility, distribution of trading volumes and intervals, etc. have been systematically and quantitatively demonstrated. [5–9]. A general consequence of such findings is that these features cannot be reproduced in the context of a single agent framework. Thus a great afford is addressed to developing approaches to study artificial financial markets based on interacting heterogeneous agents.

According to the classical approach, simple analytically tractable models with representative, perfectly rational agents have been the main cornerstone. Conversely, a new behavioral approach, where markets are populated by boundedly rational, heterogeneous agents using rule of thumb strategies, fits much better with agent-based simulation models. In this framework, computational and numerical methods have become important tools of analysis. Over the last 15 years, a number of computer-simulated, artificial financial markets have been put forward. Following the pioneering work done at the Santa Fe Institute [10,11], a large number of researchers have proposed models for artificial markets populated with heterogeneous agents endowed with learning and optimization capabilities. This lead to several examples of artificial stock markets proposed in the literature, e.g., Santa Fe Institute Artificial Stock Market [12] and the Genoa Artificial Stock

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doi:10.1016/j.nonrwa.2010.09.018

Market (GASM) [13–15]. LeBaron [16] offers a review of recent work in this field. Generally speaking, in the framework of artificial stock markets, attention has been focused mostly on single asset artificial stock markets, in order to understand and reproduce the stylized-facts of univariate price processes. Only recently, an extension to a multi-asset environment populated by zero-intelligence traders has been proposed. Computational experiments pointed out the possibility to reproduce some stylized facts both in terms of the single price process and of the aggregate behavior. However, results suggested a reduced capability in reproducing the well known unitary root stylized fact, as it was obtained only in the presence of exogenous cash inflow.

This limitation can be overcame employing recent results on a single-asset artificial stock market based on information propagation [17]. Indeed, the information-based artificial stock market was able to reproduce the main stylized facts of univariate financial time-series (including unitary root) in an endogenous framework [17]. This paper deals with a multi-asset framework, where the heterogeneous agents are seen as nodes of sparsely connected graphs. The market is characterized by different types of stocks, where agents trade risky assets in exchange for cash. Each agent is characterized by sentiments besides the amount of cash and of assets owned. Moreover, agents share their sentiments by means of interactions that are determined by graphs. Agents are subject to a portfolio choice on number and type of risky securities. The allocation strategy is based on sentiments and wealth. A central market maker (clearing house mechanism) determines the price processes for each stock at the intersection of the demand and supply curves.

The validation method followed in this paper is the capability of the information-based artificial stock market to reproduce the stylized facts for univariate and multivariate price processes. Concerning univariate processes, three main stylized facts are taken as reference: unitary root of price processes, fat-tail distribution of returns and volatility clustering. The multi-assets environment offers a new set of stylized facts for validation, i.e., the statistical properties of cross-correlation matrices of returns [18–23] and of variance–covariance matrices of prices [24], that make reference to static and dynamic factors, respectively.

The computational experiments discussed in this paper show that the main statistical properties of univariate and multivariate price processes are reproduced in an endogenous framework. This points out the importance of connection structure among the agents. It is worth remarking on the importance of this result, as for the first time, an artificial stock market reproduces endogenously all these features.

The paper is organized as follows: Section 1 presents the model, Section 2 shows the model validation and the discussion of results and Section 3 provides the conclusion of the study.

1. Model

In this section, the model of an informed multi-assets artificial stock market is presented. The model makes reference to the Genoa Artificial Stock Market—GASM. Heterogeneous and informed agents trade risky assets in exchange for cash depending on the interactions among agents. They are modeled as liquidity traders, i.e., the decision making process is constrained by the finite amount of financial resources (cash + stocks) they own. At the beginning of the simulation, cash and stocks are distributed randomly among agents.

1.1. Agents' world and sentiments

Let K be the number of assets, k denote the particular asset and S_i^k be the sentiment of agent i about the asset k.

Let I be the number of agents organized in N groups homogeneous for information and wealth, according to a Zipf law. The n-th group has rank n and is composed by n agents, so that the total number I of agents is equal to $N(N+1)/2$. The importance of each agent is approximately inversely proportional to its rank and all the parameters of the agents are calculated according to such a ranking, including the initial endowment of cash and assets. For each stock an agent is randomly connected to a set of other agents whose number and strength (of the connection) g_{ij}^k are inversely proportional to his rank, i.e., richer agents influences a larger number of agents with a higher strength. Consequently, the output degree distributions over the nodes are set to power laws and the input degree distributions result in power laws too.

Each agent has a different belief about the K assets depending on his rank. For each asset, the agents are organized according to a directed random graph, where the agents are the nodes and the branches represent the interactions among agents. The graphs are responsible for the changes in agent's sentiments. The graphs are directed, i.e., the interactions are assumed unidirectional (i.e., if agent j influences agent i it does not necessarily mean that agent i influences agent j) and characterized by a strength g_{ji}^k, assumed a positive real number. Generally speaking, due to the presence of a directed graph, both an output node degree, related to the output branches of a given node, and an input node degree, related to the input branches, should be defined.

At each time step h, information is propagated through the market and sentiments S_i^k of agent i are updated. S_i^k are real numbers in the interval $[-1, 1]$. Let $\Im_i^k$ be the set of agents that influence the behavior of agent i for the asset k and p^k the market price of the risky asset k. The new sentiments S_i^k of agent i for each asset are functions of the previous sentiments, of the influence of interacting agents, of the log return (market feedback) and of average sentiment of the agent about the market behavior. The expression is

$$S_i^k(h) = F[\alpha_{1,i} S_i^k(h-1) + \alpha_{2,i} \hat{S}_i^k(h-1) + \alpha_{3,i} r^k(h-1) + \alpha_{4,i} \tilde{S}_i(h-1)] \tag{1}$$