Expert Systems with Applications 41 (2014) 7436–7454

Contents lists available at ScienceDirect

Expert Systems with Applications

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

A note on the relationship between market efficiency and adaptability – New evidence from artificial stock markets

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ARTICLE INFO

Article history:
Available online 11 June 2014

Keywords:
Efficient Market Hypothesis
Adaptive Market Hypothesis
Agent-based modelling
Artificial stock markets
Genetic Programming

ABSTRACT

We developed various artificial stock markets populated with different numbers of traders using a special adaptive form of the Strongly Typed Genetic Programming (STGP)-based learning algorithm. We then applied the STGP technique to historical data from three indices – the FTSE 100, S&P 500, and Russell 3000 – to investigate the formation of stock market dynamics and market efficiency. We used several econometric techniques to investigate the emergent properties of the stock markets. We have found that the introduction of increased heterogeneity and greater genetic diversity leads to higher market efficiency in terms of the Efficient Market Hypothesis (EMH), demonstrating that market efficiency does not necessarily correlate with rationality assumptions. We have also found that stock market dynamics and nonlinearity are better explained by the evolutionary process associated with the Adaptive Market Hypothesis (AMH), because different trader populations behave as an efficient adaptive system evolving over time. Hence, market efficiency exists simultaneously with the need for adaptive flexibility. Our empirical results, generated by a reduced number of boundedly rational traders in six of the stock markets, for each of the three financial instruments do not support the allocational efficiency of markets, indicating the possible need for governmental or regulatory intervention in stock markets in some circumstances.

1. Introduction

A few decades ago, the Efficient Market Hypothesis (EMH) was very widely accepted by academic financial economists. In broad terms, the EMH postulates that market prices should reflect all available information. As a consequence, market prices should always be consistent with their fundamental values. The hypothesis was independently developed by Samuelson (1965), Fama (1963, 1965a, 1965b, 1970). Samuelson (1965) generated a series of non-linear programming solutions to spatial pricing models with no uncertainty, and proposed that in informationally efficient markets price changes are unpredictable if market prices fully incorporate the information disseminated from all market participants. Since then, the concept of efficient markets has been applied to many theoretical models and empirical studies of asset prices, generating several controversial debates.

Advocates of the EMH, such as Jensen (1978), have argued that there is no other proposition in economics which has more solid supporting empirical evidence than the EMH. In the late 1970s, the EMH continued its transition from theory to doctrine. Thompson (1978), Galai (1978), Charest (1978) and Davidson and Froyen (1982), and in the early 1990s, Nichols (1993), Conrad (1995) and Shanken and Smith (1996) provided evidence that supported the EMH. Malkiel (2003) suggested that stock markets are more efficient and rather less predictable than many academic studies would have us believe.

By the beginning of the twenty-first century, the academic dominance of the EMH had somewhat diminished. A group of researchers equipped with anomalous evidence inconsistent with the EMH suggested that the EMH should be replaced by a behavioural finance approach (Haugen, 1999; Koonce, 2001; Schleifer, 2000; Thaler, 1993; Shiller, 2003). In the behavioural approach investors are not necessarily assumed to be rational utility maximising agents but instead may have behavioural biases. In this context, it has been empirically observed that financial markets do not process information instantaneously (Chan, Jegadeesh, & Lakonishok, 1996), and that markets can overreact as a result of investor optimism or pessimism (Dissanaike, 1997). Furthermore, many empirical studies support the fact that markets are predictable even on the basis of past market prices (Brock,

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http://dx.doi.org/10.1016/j.eswa.2014.06.004
0957-4174/

Lakonishok, & LeBaron, 1992; Chiarella & He, 2003; Jegadeesh & Titman, 2001).

The controversy intensified and researchers began to question whether the EMH could ever be validated or discredited (Langevoort, 1992).

Some researchers has investigated the properties of agents and their interactions with more sophistication than either the EMH or standard behavioural finance. The concepts of heterogeneity, bounded rationality, and evolutionary adaptive agents have been explored by Brock and Hommes (1997a, 1997b, 1998a, 1998b), Chiarella and He (2002a, 2002b), Gaunersdorfer and Hommes (2000) and Hommes (2001). A few years later, in an attempt to accommodate most of the complexities of the real world, Lo (2004) and Lo (2005) proposed the Adaptive Market Hypothesis (AMH). This hypothesis modifies the EMH paradigm to suggest that the forces that drive prices to their efficient levels are not always dominant and the processes of learning, competition and evolutionary selection pressures govern these forces.

Nevertheless, the majority of the studies related to market efficiency and adaptability have a major shortcoming. They have failed to investigate the relation between market diversity and market efficiency, and the impact of individual learning and adaptability on the diversity of traders' expectations. Chen and Yeh (2001) expressed the view that market size could potentially have a dramatic impact on market efficiency. The questions our study is trying to answer are whether market organisation influences traders' strategies and in turn market efficiency, and whether market structure affects individual learning in the AMH.

In this study, we developed ten stock markets, each populated by different numbers of artificial traders, for each of the FTSE 100, S&P 500 and Russell 3000 indices. We also implemented a special adaptive learning form of Genetic Programming (GP) called Strongly Typed Genetic Programming (STGP), in order to investigate the relationship between market efficiency and adaptability (the computational nature of GP and STGP is described in Appendices A and B). The reason for using STGP is because Lo (2004) and Lo (2005) regarded the market as an evolutionary process where the principles of evolution such as competition, adaptation, and natural selection are applicable to financial markets. In this sense, the artificial traders in our experiment can be considered to be agents that adapt, learn, evolve, and try to survive. The random nature of the initial trading rules of the agents allowed us to observe how they learn, adapt, and survive (the worst performing traders were replaced).

The scientific advantage of the STGP over conventional GP used in most studies so far is that STGP evaluates the fitness of agents through a dynamic fitness function which processes the most recent data (quotes of the three indices in our experiment), rather than a re-execution of the same trading rules.

We then empirically evaluated the price series of these three indices to investigate the relationship between markets populated by different numbers of heterogeneous agents with different dynamics and the validity of the EMH and the AMH. We also explored the dynamic behaviour of the models when testing for the presence of nonlinearity.

Despite the voluminous literature on the topic, no other study has implemented the STGP technique with a large number of artificial agents, which has enabled us to develop of a wider variety of trading rules. Our financial markets can, therefore, be viewed as co-evolving ecologies of different trading strategies. These strategies are analogous to a biological species, and the amount of funds deployed by traders following a given strategy is analogous to the population of that species (Farmer & Lo, 1999). The presence of 10,000 heterogeneous and interacting adaptive traders, rich in dynamics, provides the opportunity to study the stock market as a complex adaptive system. Artificial traders are, by definition, capable of adapting, learning, and evolving, which makes them extremely suitable for the analysis of market efficiency and adaptability, because adaptation and learning in heterogeneous structures are known as important tools for analysing financial market behaviour (Hommes, 2001). Hommes (2011) argued that heterogeneity is a critical aspect of the theory of expectations, because a model of heterogeneous expectations can explain different aggregate outcomes across different market settings.

To summarise, the contributions of this study are as follows. Firstly, we are the first to apply the STGP technique in the analysis of market efficiency and adaptability, whilst taking into account different market structures and individual trader cognitive abilities and heterogeneity. Recent studies, such as Urquhart and Hudson (2013), Soufian, Forbes, and Hudson (2013), Zhou and Lee (2013), Zhou, Gu, Jiang, Zhang, and Zhou (2014), Ghazani and Aragli (2014), Verheyden, Van den Bossche, and De Moor (2014) and Hull and McGroarty (2014), suggest that the AMH better describes the behaviour of stock returns than the EMH.

However, these authors based their conclusions entirely on econometric tests or theoretical hypotheses only, and failed to observe the processes of adaptation, learning, competition, and evolutionary selection pressures that govern the AMH. Our study aimed to fill this gap by providing significant empirical findings combined with evidence gained from evolutionary dynamic processes.

Secondly, the conditions under which the EMH or the AMH are appropriate have not been appropriately studied. We hope that the solid empirical evidence that we present will shed light on the formation of stock market dynamics and the formalisation of both hypotheses within artificial laboratory stock market settings.

Thirdly, we have found that different trader populations behave as an efficient adaptive system. We observed that market efficiency is not necessarily associated with rational assumptions and that nonlinear dependence in index returns evolve over time. Hence, we think that market efficiency is not a static characteristic as assumed in most of the studies published so far. Our findings are consistent with the perception of financial markets as adaptive systems subject to evolutionary selection pressures. Emerson, Hall, and Zalewska-Mitura (1997) and Zalewska-Mitura and Hall (1999) see markets as a continuous process of evolving efficiency and when market participants become more experienced the level of efficiency will gradually improve.

The remainder of this paper is organised as follows: Section 2 presents the background and a review of the literature in the field together with some discussion on the relevant contributions of this study; Section 3 discusses the experimental design; Section 4 discusses the simulation results and the paper concludes in Section 5.

2. Background

2.1. Origins and supporting empirical evidence on the EMH

In this subsection we discuss the history of the EMH and the empirical evidence supporting the hypothesis.

More than a century ago, Bachelier (1900) analysed the mathematical theory of random processes and expressed the view that stock price movements follow a Brownian motion and that, therefore, stock prices are unpredictable. Many years later, Samuelson (1965) generated a series of non-linear programming solutions to spatial pricing models with no uncertainty, and proposed that the price changes in informationally efficient markets are unpredictable if market prices fully incorporate the information disseminated from all market participants.

In four different seminal papers, Fama (1963), Fama (1965a), Fama (1965b) and Fama (1970) measured the statistical properties