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Interfaces with Other Disciplines

Fuzzy adaptive decision-making for boundedly rational traders in speculative stock markets

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ABSTRACT

The development of new models that would enhance predictability for time series with dynamic time-varying, nonlinear features is a major challenge for speculators. Boundedly rational investors called "chartists" use advanced heuristics and rules-of-thumb to make profit by trading, or even hedge against potential market risks. This paper introduces a hybrid neurofuzzy system for decision-making and trading under uncertainty. The efficiency of a technical trading strategy based on the neurofuzzy model is investigated, in order to predict the direction of the market for 10 of the most prominent stock indices of U.S.A, Europe and Southeast Asia. It is demonstrated via an extensive empirical analysis that the neurofuzzy model allows technical analysts to earn significantly higher returns by providing valid information for a potential turning point on the next trading day. The total profit of the proposed neurofuzzy model, including transaction costs, is consistently superior to a recurrent neural network and a Buy & Hold strategy for all indices, particularly for the highly speculative, emerging Southeast Asian markets. Optimal prediction is based on the dynamic update and adaptive calibration of the heuristic fuzzy learning rules, which reflect the psychological and behavioral patterns of the traders.

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1. Introduction

Ever since the introduction of the Efficient Markets Hypothesis, fully rational agents were considered the driving forces of markets, which in turn operated in a way to aggregate and process the beliefs and demands of traders reflecting all available information (Fama, 1970; Fama, 1991). But the empirical evidence from financial markets was not in full accordance with the Efficient Markets Hypothesis. The alternative heterogeneous agents' behavioral model is based on relaxing strict rational agent assumptions and introducing market frictions. Simon (1957) claimed that, boundedly rational agents using simple rules-of-thumb, provides a more accurate and realistic description of human behavior than perfect rationality with optimal decision rules. La Porta et al. (1997); Cenci et al. (1996) and Shiller (2002) argue that stock prices predictability reflects the psychological factors and fashions or fads of irrational investors in a speculative market. Similar results are reported in more recent studies of Madura and Richie (2004) and Sturm (2003). Overall, the study of bounded rationality and the rapid growth of the new field of behavioural economics over the past two decades led to the award of the Nobel Prize to V. Smith and D. Kahneman in 2002. The irrational market behavior has also been emphasized by Shleifer and Summers (1990) and Black (1986) in their exposition of noise traders who act on the basis of imperfect information and consequently cause prices to deviate from their equilibrium values. In general, there are two types of agents in heterogeneous agent models: "fundamentalists", who base their expectations upon dividends, earnings, growth or even macroeconomic factors, and "chartists" (noise traders and technical analysts) who instead base their trading strategies upon historical patterns and heuristics and try to extrapolate trends in future asset prices (Brock and Hommes, 1998; Hommes, 2005). The present study focuses on the latter. Specifically, the predictive return sign ability of trading rules that rely on a simple switching strategy is investigated: positive predicted returns are executed as long positions and negative returns as short positions. A similar strategy has been employed, with considerable success, by a number of other researchers (Gençay, 1998b; Gençay, 1998a; Fernández-Rodriguez et al., 2000) etc. In general terms they find that the returns from the switching strategy are higher than those from the passive one for annual returns, even when transaction costs are high. They also find that the asset return predictability is increased during volatile periods. The buy and sell signals are produced from technical trading strategies that incorporate various linear or non-linear econometric models.

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2. Nonlinear modeling and forecasting with neural networks and fuzzy inference systems

The major challenge for "chartists" is the development of new models, or the modification of existing methods, that would enhance forecasting ability particularly for time series with dynamic time variant patterns. Conventional time series analysis, based on stationary stochastic processes does not always perform satisfactorily on economic and financial time series (Harvey, 1989). The reason is that economic data are not generally described by simple linear structural models, white noise or even random walks. The most commonly used techniques for financial forecasting are Regression methods and Autoregressive Moving Average (ARMA) models (Box and Jenkins, 1970). These methods have been used extensively in the past, but they often fail to give an accurate forecast for some series because of their nonlinear structures and some other inherent limitations. Even though ARCH/GARCH models (Bollerslev, 1986) deal with non-constant variance, still some series cannot be explained or predicted satisfactorily, due to inherent chaotic or noise patterns, fat tails, or other nonlinear components.

Extensive research in the area of nonlinear modeling has shown that neural networks enhance financial forecasting, mainly because they perform advanced mathematical and statistical processes such as nonlinear interpolation and function approximation. Neural networks are parallel computational models comprising input and output vectors as well as processing units (neurons) interconnected by adaptive connection strengths (weights), trained to store the "knowledge" of the network. Adya and Collopy (1998) demonstrated the advanced predictive ability of neural networks for time series forecasting. White (1989) and Kuan and White (1994), suggested that the relationship between neural networks and conventional statistical approaches for time series forecasting is complementary. Additionally, the function approximation properties of neural networks have been thoroughly investigated by many authors. The results in Cybenko (1989); Funahashi (1989); Hornik (1991); Hornik et al. (1989); Gallant and White (1992) and Hecht-Nielsen (1989) demonstrated that feedforward networks with sufficiently many hidden units and properly adjusted parameters can approximate any function to any desired degree of accuracy. Poddig (1993) applied a feedforward neural network to predict the exchange rates between American Dollar and Deutsche Mark, and compared results to regression analysis. Other examples using neural networks in stock and currency markets include Gençay (1998); Green and Pearson (1994); Rawani (1993); Weigend (1991); Yao et al. (1996) and Zhang (1994). However, conventional time series analysis techniques as well as neural networks incorporate in terms of input variables, only quantitative factors, such as stock returns, indices and other financial or economic magnitudes. A number of qualitative factors, e.g., macroeconomical or political effects as well as traders psychology may seriously influence the market trend, thus it is important to capture this inherent knowledge.

Fuzzy logic has been implemented initially in the area of control systems and decision theory and recently in economic applications with highly promising results. It provides a means of decision-making and learning under uncertainty. Specifically, in a fuzzy system numeric variables (inputs and outputs) are translated into fuzzy linguistic terms representing beliefs, e.g. "low" and "high". Each term is described by a membership function, which estimates the "degree" to which a variable belongs to a fuzzy set. Finally, fuzzy inference rules represented in IF–THEN statements are specified to associate the fuzzy input to the output fuzzy set. The specification of the rules could comprise an efficient mechanism of incorporating expectations and beliefs. In general, Fuzzy systems are widely applied in fields like classification, decision support, process simulation and control systems, exactly because are effective means of modeling human expert knowledge, experience, intuition, etc., (Slowinski, 1993; Slowinski and Stefanowski, 1994; Sugeno, 1988; Kosko, 1992; Klir and Yuan, 1995; Jamshidi et al., 1997; Mamdami, 1974; Mamdami, 1977). Financial and marketing applications have also been reported (Hashemi et al., 1998; Altrock, 1997). One important advantage of fuzzy inference systems is their linguistic interpretability. When implementing fuzzy systems, the focus is paid on modeling fuzziness and linguistic vagueness using membership functions. The fuzzy system approach has been applied to different forecasting problems whereby the operator's expert knowledge is used for prediction (Kaneko and Takaomi, 1996; Al-Shammari and Shaout, 1998). Although the fuzzy logic-based forecasting shows promising results, the process to construct a fuzzy logic system is subjective and depends on some ad-hoc assumptions. The learning rules derived in this way may not always yield the best forecast, and the choice of membership functions depends on trial and error. Neural networks' learning ability can be utilized to adjust and fine-tune the fuzzy membership functions. The combination of both techniques results in a hybrid neurofuzzy model which incorporates the learning ability of the neural network and the functionality of the fuzzy expert system. In a neurofuzzy system the basic concept is the derivation of various parameters of a fuzzy inference system by means of adaptive training methods obtained from neural networks (Buckley and Hayashi, 1994; Nishina and Hagiwara, 1997). Recent applications of neurofuzzy models for the prediction of financial prices and volatility can be found in the works of Pantazopoulos et al. (1998); Jalili-Kharaajoo (2004) and Cheng et al. (2007).

The present study advances the literature that has utilized separately neural networks or fuzzy logic systems in financial forecasting applications, by presenting a hybrid neurofuzzy approach that leads to superior predictions upon the *direction-of-change* of the market. The purpose of this paper is to illustrate this concretely through an investigation of the relative direction-of-change predictability of the proposed neurofuzzy trading model compared to other well-established nonlinear models. Finally, this study also provides a significant advancement of an earlier one by Bekiros and Georgoutsos (2007).

The remainder of this paper is organized as follows: Section 3 describes how the neurofuzzy model for "heuristic trading" is constructed. In Section 4 the other forecasting models used in this study are described. Finally, the empirical results are shown in Sections 5 and 6 provides concluding remarks.

3. Decision-making under uncertainty: a hybrid neurofuzzy inference model

The neurofuzzy architecture consists of the input, the rule layer and the output layer. In the input fuzzy layer all the input variables are translated into fuzzy linguistic terms. Each term is described by fuzzy membership functions. The type of membership functions is configured in this layer, whereas the parameters of these functions are processed and optimized via neural network training. Fuzzy learning, represented in IF–THEN statements, is specified to associate input and output variables of a system, which in this case is a heterogeneous financial market, while modeling psychology patterns and intuition of the agent. Consequently, the IF–THEN rules' set-up provides a very realistic model of the decision-making process under which rule-of-thumb traders operate. The rules modeled in the fuzzy rule layer consist of two parts, the "IF" part and "THEN" part. The "IF" part utilizes an "AND" association. This operator proposed by Zimmerman and Thole (1978) represents the minimum value among all the validity values of the "IF" part. The output fuzzy layer incorporates the fuzzy membership

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