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Innovative Applications of O.R.

Forecasting foreign exchange rates with adaptive neural networks using radial-basis functions and Particle Swarm Optimization

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ABSTRACT

The motivation for this paper is to introduce a hybrid neural network architecture of Particle Swarm Optimization and Adaptive Radial Basis Function (ARBF–PSO), a time varying leverage trading strategy based on Glosten, Jagannathan and Runkle (GJR) volatility forecasts and a neural network fitness function for financial forecasting purposes. This is done by benchmarking the ARBF–PSO results with those of three different neural networks architectures, a Nearest Neighbors algorithm (k-NN), an autoregressive moving average model (ARMA), a moving average convergence/divergence model (MACD) plus a naïve strategy. More specifically, the trading and statistical performance of all models is investigated in a forecast simulation of the EUR/USD, EUR/GBP and EUR/JPY ECB exchange rate fixing time series over the period January 1999–March 2011 using the last 2 years for out-of-sample testing.

As it turns out, the ARBF–PSO architecture outperforms all other models in terms of statistical accuracy and trading efficiency for the three exchange rates.

1. Introduction

Neural Networks (NNs) are an emergent technology with an increasing number of real-world applications including operational research (Lisboa and Vellido, 2000; Zhang et al., 1998). However their numerous limitations and contradictory empirical evidence around their forecasting power are often creating scepticism about their use among practitioners. This scepticism is further fueled by the fact that the selection of each algorithm parameters and inputs is based more on trial and error and the practitioner's market knowledge rather than on some formal statistical procedure.

The motivation for this paper is to introduce in Operational Research a hybrid neural network architecture of Particle Swarm Optimization and Adaptive Radial Basis Function (ARBF–PSO), which try to overcome some of these limitations. More specifically our proposed architecture is fully adaptive something that decreases the numbers of parameters that the practitioner needs to experiment while on the other hand it increases the forecasting ability of the network. The proposed methodology is superior in comparison to the application of meta-heuristic methods (PSO, Genetic Algorithms, Swarm Fish Algorithm) that have been already presented in the literature (Nekoukar and Beheshti, 2010; Shen et al., 2011) because it eradicates the risk of getting trapped into local optima and the final solution is assured to be optimal for a subset of the training set.

In our study we benchmark our proposed algorithm with a Multi-Layer Perceptron (MLP), a Recurrent Neural Network (RNN), a Psi Sigma Neural Network (PSI), a Nearest Neighbors algorithm (k-NN), an autoregressive moving average model (ARMA), a moving average convergence/divergence model (MACD) plus a naïve strategy in a forecasting and trading simulation of the EUR/USD, the EUR/GBP and the EUR/JPY European Central Bank (ECB) daily fixing. The main reason behind our decision to use the ECB daily fixings is that it is possible to leave orders with a bank and trade on that basis. It is therefore a tradable quantity which makes our trading simulation more realistic. We examine the exchange rates from their first trading day since the end of April 2011. Moreover, the nonlinearities and the high complexity of the exchange rates series make them perfect for a forecasting exercise. Nevertheless our proposed methodology can be applied to any forecasting task irrespective the nature of the series under study.

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Moreover, we introduce a time-varying leverage trading strategy based on GJR (1993) model volatility forecasts and examine if its application can increase the trading efficiency of our models.

We also introduce a fitness function for our NNs that not only minimize the MSE of our forecasts but also increase their profitability. This is crucial in financial applications where statistical accuracy is not always synonymous with financial profitability of the derived forecasts.

As it turns out the ARBF–PSO algorithm does remarkably well and outperforms all other models in terms of statistical accuracy and trading efficiency for the time series and period under study. It seems that its adaptability and flexibility allows it to outperform in our forecasting competition compared with the more 'traditional' k-NN, MLP, RNN and PSI models. These results provide the first empirical evidence around the utility of the ARBF–PSO in finance and forecasting.

The rest of the paper is organized as follows. In Section 2 we present some relevant recent applications in forecasting and Section 3 describes the dataset used for this research and its characteristics. An overview of the proposed model and the NN and statistical benchmarks is given in Section 4. Section 5 gives the empirical results of all the models considered and investigates the possibility of improving their performance with the introduction of a sophisticated trading strategy while Section 6 provides some concluding remarks.

2. Literature review

Developing high accuracy techniques for predicting time series is a very crucial problem for scientists and decision makers. The traditional statistical methods seem to fail to capture the discontinuities, the nonlinearities and the high complexity of datasets such as financial time series. Complex machine learning techniques like Artificial Neural Networks (NNs) provide enough learning capacity and are more likely to capture the complex non-linear models which are dominant in the financial markets but their parameter tuning remains difficult and generalization problems exist (Donaldson and Kamstra, 1996; Lisboa and Vellido, 2000).

The main objective of this paper is to introduce a novel hybrid method which is able to overcome the difficulties in tuning the parameters of artificial neural networks. For this purpose among the various neural network techniques, we use the Radial Basis Function Neural Networks (RBFNNs) which has proven experimentally to outperform the more classical NNs architectures (Broomhead and Lowe, 1988). The hybrid method combines the RBFNNs with Particle Swarm Optimization (PSO) algorithm, a state-of-the art heuristic optimization technique (Kennedy and Eberhart, 1995) in a way that optimizes the neural networks parameters, structure and training procedure. Our proposed methodology is an extension of the algorithm proposed by Ding et al. (2005) for forecasting purposes.

The proposed methodology has not been applied in science yet. However, two approaches have been recently proposed for the optimization of RBF neural networks and their application in financial time-series forecasting. Nekoukar and Beheshti (2010) propose the application of a modified PSO (using hunter particles to increase diversity) for training Radial Basis Functions. This methodology was applied for the prediction of the price of Iranian stock time-series. Despite the high prediction accuracy of the derived model, this hybrid technique does not provide any method for optimizing the structure of the RBF network. Moreover, the applied PSO algorithm uses constant parameters, which requires an extra time-consuming optimization step. Shen et al. (2011) introduce a novel hybrid technique which applies an Artificial Fish Swarm algorithm to train Radial Basis Function Neural Networks for modeling the Shanghai Composite Indices. The prediction results are extremely good, but the artificial fish swarm algorithm is not used for the optimization of the RBF network's structure and it requires some parameters to be tuned via a time consuming trial and error approach. Compared to a simple genetic algorithm and a simple PSO method which are also used to train Radial Basis Function Neural Networks, the Artificial Fish Swarm algorithm produces a slightly higher prediction error but the authors believe that being a new intelligent algorithm it has room for improvement and development. Both of these methods use Mean Square Error as a fitness function and they are not specialized for the prediction of financial time series contrary to our proposed methodology.

Several scientists have applied other NNs algorithms to the task of forecasting financial series with ambiguous empirical evidence. Fulcher et al. (2006) apply Higher Order Neural Networks in forecasting the AUD/USD exchange rate with a 90% accuracy. Panda and Narasimhan (2007) use a single hidden layer feedforward NN to produce statistical accurate forecasts of the INR/USD exchange rate having several linear autoregressive models as benchmarks while Andreou et al. (2008) use NNs to forecast and trade European options with disappointing results. On the other hand, Kiani and Kastens (2008) forecast the GBP/USD, the CAD/USD and the JPY/USD exchange rates with feedforward and recurrent NNs having as benchmarks several ARMA models. In their application, NNs outperform in statistical terms their ARMA benchmarks in forecasting the GBP/USD and USD/JPY but not in forecasting the USD/CAD exchange rate. Yang et al. (2008) employ a NN and other regression techniques to examine the potential martingale behavior of Euro exchange rates in the context of out-of-sample forecasts. The overall evidence indicates that, while martingale behavior cannot be rejected for Euro exchange rates with major currencies such as the Japanese yen, British pound, and US dollar, there is nonlinear predictability in terms of economic criteria with respect to several smaller currencies (such as the Australian dollar, the Canadian dollar and the Swiss franc). Bekiros and Georgoutsos (2008) forecast and trade successfully the NASDAQ index with RNNs and Yang et al. (2010) study the predictability of eighteen stock indexes with NNs and linear models. Their models demonstrate low predictability when the data snooping bias was considered. On the same year while on the same year Huck (2010) combines NNs with a multi-criteria decision making method in a S& P 100 stock pair trading application with good results. Adeodato et al. (2011) won the NN3 Forecasting Competition problem with an innovative approach based on the use of median for combining MLP forecasts and Matias and Reboredo (2012) forecast successfully with NNs and other nonlinear models intraday stock market returns. In a forecasting competition, Dunis et al. (2010), Dunis et al. (2011) and Sermpinis et al. (in press) compare several Higher Order NNs and autoregressive models in forecasting and trading the EUR exchange rates. Their results demonstrate the forecasting superiority of a class of NNs, the Psi Sigma, which are able to capture higher order correlation within their dataset. Bekiros (2010) introduced a promising hybrid neurofuzzy system which forecast accurately the direction of the market for 10 of the most prominent stock indices of USA, Europe and Southeast Asia and Dhamija and Bhalla (2011) apply several variants of the MLP and RBF networks to the task of forecasting five different exchange rates with good results. On the same year Wang et al. (2012) forecast successfully the Shenzhen Integrated Index and the Dow Jones Industrial Average Index with a hybrid NN model. Compared to the above mentioned studies, our proposed algorithm is fully adaptive and enables us to avoid the time consuming and risky process of optimizing the parameters of our networks through a sensitivity analysis in the in-sample period. However, we apply some of the most promising architectures of the previous mentioned paper such as the Psi Sigma (Fulcher et al., 2006; Dunis et al., 2010; Dunis