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Abstract—Undoubtedly, stock market prediction constitutes one of the most popular and prominent problems that concern a multidisciplinary audience. Indeed, various disciplines participate in this intriguing exercise including Economics, Statistics and Computer Science. Furthermore, the proliferation and high performance of machine learning methodologies and especially, deep learning techniques, have led the research community to adopt them in time-series forecasting such as stock prices. For this reason, a Systematic Literature Review (SLR) is conducted including primary studies that deal with the prediction of stock markets in the European Union (EU), using deep learning techniques. The proposed SLR involves 12 papers, indicating that there is not yet intense activity in this field, which thus appears open for further research.

Index Terms—Deep Learning, Stock Market, Systematic Literature Review

Type of the Submission: "Full/Regular Research Papers"
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I. INTRODUCTION

The prediction of stock prices has been an area of great interest over the last years because of the complexity such a problem presents, and the practical financial opportunities it offers. Recently, a plethora of papers have been published, aiming to produce better predictions with the use of machine learning/deep learning techniques. The aforementioned techniques exploit the increasing computational power of contemporary computers and present usually better results compared to traditional time-series models [1].

Even though there exist literature reviews that try to encompass as many papers as possible in the field of machine learning/deep learning for stock price predictions, we found that those surveys include mainly data sets from the US market (mainly from S&P 500) and the emerging China market. On the other hand, the representation of EU stock markets in existing surveys is minor.

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According to a recent literature review in the research field [2], which was also the inspiration research work of the current study, the following findings could be extracted. 40%, of the papers focused on stock price or index prediction, containing at least one data set from USA stock markets and 23% of them used a data set from Chinese stock markets. In contrast, only 9% of the data sets used are related to European countries, giving to the EU, the fourth place, with respect to the frequency of published papers, behind Japan, since Japanese stock market represents the 10% of the data sets used in the literature.

Although EU stock markets are not as prosperous as US and Asian stock markets, the need for in-depth review is crucial for many reasons. In addition, we cannot neglect the prominent interest of the investors around the world for the EU stock markets. Secondly, European Union markets comprise a special case study. The fact that many interconnected stock markets are affected by various and sometimes contradictory monetary policies of their respective governments is really notable. On the other side, USA and Chinese stock markets despite their dissimilarities, they still function under the aegis of a unified country respectively.

However, at this point, it is worth mentioning that although EU is not a unified country, as described in the previous paragraph, a recent study [3] focused in the Eurozone and more specifically in the EURO STOXX 50 index, presented that there is a similar volatility pattern among Euro area stock markets, which constitute the majority of the EU stock markets (19 out of 27 stock markets belong to countries that compose the Eurozone).

Finally, the BREXIT shocked the global stock markets and made investors cautious about the future of European stock markets. Specifically, BREXIT decision had similar effect to the prosperous European stock markets, that is immediate decrease in stock prices and gradual increase to the previous state within 3 weeks [4]. However, in many stock markets the stock prices have recovered partly. This uncertain indication...
about the EU future really tests the possibilities of predictive algorithms in simulating and predicting the volatile EU stock indices.

Hence, it is undeniable that a political and economic union of 27 countries, such as the EU, which constitutes the second largest economy of the world (according to GDP [5]), deserves much more research attention with regard to the stock market prediction.

The aforementioned situation inspired the proposed study, which focuses in European stock markets, and tries to present: a) all relevant papers that have been published in the last 10 years, b) which techniques have been employed, c) which EU countries’ markets are being represented, and d) whether the sophisticated deep learning methods used show better performance compared to traditional approaches.

The remainder of the paper has the following structure: Section II presents other reviews that were found and the criteria they used for including relevant papers. In Section III, the methodology used to find the papers having been included in this review is covered. In Section IV the results are presented and finally, the last Section summarizes the findings and provides recommendations for future work.

II. RELATED WORK

As already mentioned, stock market prediction constitutes a research area of major importance. For this reason, text mining, machine learning and deep learning techniques have been proposed the last years in this research field and subsequently, many surveys have intended to gather up all this knowledge and present it in a formal way.

Many reviews have concentrated on Machine Learning (ML) algorithms for financial prediction. For example, Strader et al. [6], reviewed journal articles from the past twenty years resulting in four ML approaches, namely Support Vector Machines (SVM), Artificial Neural Networks (ANN), Genetic Algorithms combined with other techniques and hybrid methods. Concerning ANN, Li and Ma [7] reviewed ANN implementations for stock price forecasting and other financial applications. Finally, Shah et al. [8] offer a more general view in stock markets and taxonomy of stock market prediction methods. They investigated technical, fundamental both long and short term approaches for stock prediction.


Deep Learning (DL) has rapidly emerged as a powerful tool in order to model and predict the volatile stock markets worldwide. Numerous DL methods, such as Long Short Term Memory (LSTM), Convolutional Neural Networks (CNNs) and Recursive Neural Networks (RNNs) comprise a vast toolbox for various applications. Recently, Sezer et al. [2], focused on DL implementations for financial time series prediction, such as Deep Multi-Layer Perceptron (DMLP), RNNs, LSTMs, CNNs, Restricted Boltzmann Machines (RBMs), Deep Belief Networks (DBNs), Autoencoders (AEs) and Deep Reinforcement Learning (DRL). Moreover, a review of DL models for time series prediction was carried out by Han et al. [13], implementing and testing various time series forecasting methods on both benchmark and real-world data. Furthermore, Chong et al. [14], surveyed the advantages and disadvantages of deep learning algorithms for stock market analysis and prediction and studied the effects of three deep unsupervised feature extraction methods on stock market prediction. Finally, Jiang [15] also presented various categories of data sources, many neural network structures, common used evaluation metrics and implementations.

Although there are many surveys concerning Stock Market Prediction using Deep Learning, these reviews mainly focus on US and Asian markets, while there is no research to the best of our knowledge that focuses on EU stock markets. The present SLR tries to address this gap and to present EU stock market prediction techniques.

III. METHODOLOGY

To achieve as a complete literature review as possible, the methodology used in this work is based on the techniques that are described in [16] and [17]. In spite of the fact that these articles focus on software engineering, their procedures are generic and have been used in the literature of the stock market [18]. The 3 phases followed in this review are: Planning the Review, Conducting the Review, according to the specifications set by the previous phase and Reporting the Review. One important aspect in every SLR is the identification of the need for a review. The need for this review, which has already been stated in the Introduction, contains a multitude of reasons, from the small number of papers focusing on EU stock markets, to the possible challenges of trying to predict interconnected markets, among others.

Conducting this SLR, the following questions will be answered:

1. What is the number of papers that use deep learning/neural networks techniques to predict stock prices/movements using EU data sets for training and testing purposes?
2. Which EU countries’ stock markets do they concern?
3. What methodologies were used to predict stock prices?
4. Do these papers offer any comparisons to earlier machine learning techniques and if so how do they compare?

The search strategy used in the present review includes: the snowball technique [19], both backward and forward and the automated search in appropriate databases (Google Scholar and Connected Papers), as a complementary to the snowball technique.

Regarding the automated search in the database and specifically, the refinement of the keyword search string [18], this
is an iterative procedure that refines the string in order to find an initial set of already known papers (in this research, the initial set was derived from the research work of [2]). Hence, this process results in the following keyword string, which was used in the searches of these websites:

(deep learning) AND (stock market), (deep learning) AND (stock market indices), (deep learning) AND (European stock market indices), (deep learning) AND (DAX OR FTSE OR CAC OR ASE OR BRD OR IBEX), (Deep learning) AND (stock market prediction), European stock market prediction, stock index forecasting, (deep learning) AND (European stock indices)

During the papers’ selection, certain inclusion/exclusion criteria were selected to make sure that the results were being consistent. The inclusion criteria are: a) Papers that use deep learning techniques in EU stock markets and b) Papers that do stock price predictions. The exclusion criteria are: a) papers that use traditional ML techniques for stock prices prediction of EU, b) papers that focus on portfolio management rather than stock price prediction, c) papers that were not written in the English language and d) papers that have passed a review process.

Ultimately, with regards to the data extraction part of this review, the following information was used: a) stock market data set, b) feature set, c) period, d) region of interest e) method f) performance criteria and g) improvement over traditional ML methods

IV. RESULTS

The proposed SLR was conducted according to the procedures described in Section III. Hence, as mentioned above, the initial set of papers derived from the literature review of [2], from where 3 papers were qualified according to the criteria having set. The backward and forward snowball technique are applied in those papers and the number of papers was increased to 8. Finally, the complementary automated search, results in 4 additional papers and led the total number of primary studies to 12.

Table I displays the general characteristics of the SLR, whereas, Table II shows the methodology characteristics. From there, it is obvious that the vast majority of the included papers was published in a journal (9 out of 12), and from 2017 and afterwards (8 out of 12). 2018 was the year with the most (4) publications, while the earliest paper was from Dunis et al [20] in 2011. The time periods, used for training and testing in these papers, vary from 3 months (Borovkova and Dijkstra [21]) to 26 years in Shen et al [22]. The disparity in the length of time can be justified from the difference in data frequency used in those papers. In the former, all the data points came from 5 minutes time-intervals, whereas in the latter the data points are daily. 19 different performance criteria were used in the literature of the field. Mean Squared Error (MSE) was the most frequently used, in 5 out of 12 papers, closely followed by Accuracy and Mean Absolute Error (MAE). Both of them were used in 4 out 12 papers. 12 of the metrics are only used once and this fact constitutes the direct comparison of the efficiency of the proposed models very difficult.

In order to provide some overall statistics regarding European stock market prediction using DL and Neural Networks (NN), three aspects of the SLR are analyzed in detail. First aspect is the geographical distribution (Fig. 1), which reveals the low number of existing DL and NN implementations for the prediction of EU stock market. One cannot neglect the fact that a small EU country such as Greece, is in the second position (under Germany) regarding these studies and that for many rich EU countries (e.g. France, Spain, Italy) there is no related primary study. Second, the studies can be categorized according to the method used for prediction. Thus, in Fig. 2, it is worth noticing the superiority of LSTM regarding its frequency (almost 58%) as stock market forecasting method. This pattern follows the global trend, indicating that the LSTM method is the most usable for predicting Stock Markets worldwide [2]. Finally, in Fig. 3, some useful insights are offered with respect to the feature set that each study used. Time series is by far (almost 66% of the studies) the most common feature set for models predicting stock prices, whereas financial indicators are in the second place (over 33%). However, it is worth mentioning the partial absence of Text Mining techniques (only 2 out of 12 studies) in European Stock Market prediction. This fact is quite unexpected, due to the fact of the growing amount of studies regarding Text Mining from social media and news sites in predicting the Stock Market Indices in American and Asian Markets [2].

V. CONCLUSIONS

In this paper an SLR concerning the use of DL techniques in stock market prediction within the EU has been presented. As already discussed, the most prominent finding of this SLR is the limited amount of research works (only 12) that focus on the usage of deep learning techniques for stock market prediction in the EU markets. This finding is opposed to the large amount of research that use data from the S&P 500 or the CSI 300. Hence, this fact provides great opportunities for future researchers to experiment and check whether their proposed DL methodologies can be efficiently applied in the markets of the EU. Another important finding is the absence of papers using data from major EU economies (e.g. French, Italian, Spanish) and, at the same time, the presence of the Greek stock market with three papers setting it below the German stock market.

Regarding the DL methodologies used, the SLR highlighted a clear preference of the research community for LSTMs following the trend set by papers in other markets. Furthermore, another important conclusion is that the European stock market related papers have not extensively used text mining techniques from various sources so that they can apply sentiment analysis to aid the predictions, as only two of the papers used text mining for data extraction.

Finally, all of the aforementioned statistical findings should be taken into consideration very carefully, since it is generally difficult to generalize the findings with such a limited number
### TABLE I

<table>
<thead>
<tr>
<th>Paper</th>
<th>Type of Publication</th>
<th>Publication Year</th>
<th>Region of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>[22]</td>
<td>Journal</td>
<td>2018</td>
<td>Germany</td>
</tr>
<tr>
<td>[23]</td>
<td>Journal</td>
<td>2016</td>
<td>Romania</td>
</tr>
<tr>
<td>[25]</td>
<td>Journal</td>
<td>2018</td>
<td>Germany</td>
</tr>
<tr>
<td>[26]</td>
<td>Conference</td>
<td>2018</td>
<td>Greece</td>
</tr>
<tr>
<td>[27]</td>
<td>Journal</td>
<td>2019</td>
<td>Romania</td>
</tr>
<tr>
<td>[29]</td>
<td>Conference</td>
<td>2012</td>
<td>Balkan Countries</td>
</tr>
<tr>
<td>[31]</td>
<td>Journal</td>
<td>2019</td>
<td>Germany</td>
</tr>
</tbody>
</table>

### TABLE II

<table>
<thead>
<tr>
<th>Paper</th>
<th>Dataset</th>
<th>Dataset Period</th>
<th>Features</th>
<th>Method</th>
<th>Performance Criteria</th>
<th>Improvement over Traditional ML methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>[21]</td>
<td>EUROSTOXX 50</td>
<td>01/09/2016 - 31/12/2016</td>
<td>Text mining, financial indicators</td>
<td>LSTM, MLP</td>
<td>MDA, MAPE, Accuracy</td>
<td>-</td>
</tr>
<tr>
<td>[23]</td>
<td>BRD stock in Romanian Stock Market</td>
<td>16/01/2001 - 04/11/2016</td>
<td>Time series (OHLC)</td>
<td>LSTM</td>
<td>RMSE, MAE</td>
<td>No</td>
</tr>
<tr>
<td>[24]</td>
<td>CDAX</td>
<td>2010 - 2013</td>
<td>Text mining</td>
<td>LSTM</td>
<td>Accuracy, AUC, RMSE, MSE, MAE</td>
<td>Yes</td>
</tr>
<tr>
<td>[25]</td>
<td>DAX</td>
<td>08/12/1999 - 30/01/2017</td>
<td>Time series (OHCL), financial indicators</td>
<td>Hybrid Fuzzy-Neural Network</td>
<td>Hit Ratio</td>
<td>Yes</td>
</tr>
<tr>
<td>[27]</td>
<td>Romanian Stock Market</td>
<td>16/10/1997 - 13/03/2019</td>
<td>Financial Indicators</td>
<td>CNN, LSTM</td>
<td>Sharpe Ratio, Annualized Return with transaction costs, Annualized Volatility, Annualized Return</td>
<td>-</td>
</tr>
<tr>
<td>[28]</td>
<td>OMX 30</td>
<td>02/01/2009 - 28/04/2017</td>
<td>Time series</td>
<td>LSTM</td>
<td>RSS, Accuracy</td>
<td>Yes</td>
</tr>
<tr>
<td>[29]</td>
<td>Balkan Stock Market</td>
<td>11/2006 - 10/2010</td>
<td>Time series (OHLCVM)</td>
<td>NN</td>
<td>MSE, MAE</td>
<td>-</td>
</tr>
<tr>
<td>[31]</td>
<td>DAX</td>
<td>01/04/2010 - 30/12/2016</td>
<td>Time series</td>
<td>LSTM</td>
<td>MSE, MAE</td>
<td>-</td>
</tr>
</tbody>
</table>
Fig. 1. The Rate of Publication Count in Countries of Interest

Fig. 2. Publication Count in Model Types

Fig. 3. Publication Count in Model Feature Set
of studies. However, due to this limited amount of research, additional directions can be pursued, such as focusing on markets that have not yet been used for stock prediction, and applying improvements over the existing DL methodologies such as the use of asymmetrical loss functions or the “attention” technique.

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