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Determinants of Egypt's Stock Market Performance: Evidence from Machine Learning Algorithms

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Abstract: Stock markets play a vital role in the direction of the flow of capital and economic growth of developing economies; however, the role of various factors on the stock market is debatable and differs from country to country. This study aims to explore the macroeconomic factors that affect the performance of the Egyptian stock market from 2000 to 2023 through the comparative evaluation of six supervised machine learning algorithms: Random Forest, Support Vector Machine (SVM), Logistic Regression, Naive Bayes, K-Nearest Neighbours (KNN), and Gradient Boosting, with the inclusion of the Multilayer Perceptron (MLP) neural network as a supplementary tool. Out of the six machine learning algorithms, the neural network was found to be the most effective model to predict the Egyptian stock market performance, with a precision of 87.2% and an Area Under the Curve (AUC) of 0.872, which suggests that the Egyptian stock market behaves non-linearly and asymmetrically. According to the feature importance of the model, the lagged stock price was found to be the most important feature, contributing 18% to the overall model performance, which reflects the effect of the Keynesian concept of animal spirits and self-fulfilling prophesies rather than equity valuation based on fundamental analysis. Gross domestic product (GDP), gold price, and crude oil price were found to be the second, third, and fourth most important factors, respectively. Moreover, the parameter estimation of the neural network model revealed that the monetary factors of money supply, gold price, and the exchange rate have the highest absolute weights in the hidden layer of the network.

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1. Introduction

Stock markets represent an integral part of the architecture of modern finance and economic development. As such, stock markets act as mobilisers of savings, allocators of capital, and conveyors of information regarding the performance of corporations as well as the general economic environment, simultaneously playing the roles of indicators of the health of the economy and catalysts of productive investment (Yilmazkuday, 2025). Stock markets send signals to the economy, which can be achieved through a number of different mechanisms, such as the enhancement of liquidity, diversification of risk, mobilisation of savings, enhancement of the dissemination of information, as well as the optimisation of incentives in corporate governance (Darwish, 2025). The effectiveness of these different mechanisms depends on the interaction of a set of macroeconomic variables, which determine whether the stock market moves towards efficiency or towards a state of speculative instability.

The relationship between the macroeconomic fundamentals of an economy and the stock markets has been the focus of a large number of empirical analyses, yet the literature remains heterogeneous in its findings, given the different countries, methodologies, as well as time periods used in the different analyses. Stock markets in developed countries have generally confirmed the importance of the stock markets, given the relationship with the macroeconomic variables such as GDP growth, inflation, interest rates, exchange rates, as well as monetary aggregates (Caballero & Simsek, 2023; Gómez-Cram & Grotteria, 2022). Emerging markets, on the contrary, have a number of complexities, such as the quality of the institutional environment, the development of the financial system, as well as the presence of macroeconomic volatility, coupled with the presence of both fundamental- as well as sentiment-driven investment behaviour (Agarwal, Taffler, & Wang, 2025). Egypt represents an emerging market, given its position as the most populous Arab country, as well as the largest economy in the Middle East/North Africa region, based on nominal GDP, coupled with its stock markets, which have been marked by considerable fluctuations over the last 25 years, given the presence of structural disruptions that have impacted investor confidence, market capitalisation, as well as stock prices (Lakhani, 2016).

The capitalisation of the Egyptian stock exchange was about 107% of the GDP by the year 2007, during a period when the economy was undergoing significant financial expansion, experiencing the effects of the global commodity price boom, as well as enjoying conducive regional investment environments. The 2008 GFC, however, saw the stock exchange experience an unprecedented contraction, as the EGX30 fell by 50%, thus marking the beginning of the de-leveraging process for the Egyptian economy. The subsequent events that affected the Egyptian economy include the revolution that took place in the country in January 2011, which saw the political environment become unstable, thus negatively impacting investor sentiments. The flotation of the Egyptian pound, which was enforced by the government in November 2016 as part of the IMF structural adjustment program, also negatively impacted the stock exchange, as the Egyptian pound was highly volatile during the period. The COVID-19 pandemic, which affected the world between 2020 and 2021, negatively impacted the economy, as the prices of commodities went up due to the Russia-Ukraine war, thus causing inflation, which negatively impacted the purchasing power of the Egyptian people by 2022. The stock exchange was de-capitalised by 2024, standing at 11% of the GDP, thus raising critical questions about the structural and behavioural factors that could be causing the de-capitalisation of the Egyptian stock exchange.

Thus, in the case of the Egyptian stock market, it is not sufficient to merely establish the macroeconomic correlations; it is essential to differentiate the contribution of the fundamentals, monetary factors, commodity price shocks, and behavioral effects in a complex system that is nonlinear in nature. However, the application of the traditional econometric techniques such as vector autoregression, cointegration, and panel data modeling is limited in the sense that it is linear in nature and may not be appropriate in the case of the stock market, which exhibits non-linearities, structural breaks, and regime shifts in the data (Bhowmik & Wang, 2020). However, the application of the ML techniques is non-parametric in nature and can capture the non-linear interactions among the high-dimensional features without any assumption about the functional form, as discussed in the study by Sibindi, Mwangi, & Waititu (2023). Despite the advantages that the application of the ML techniques has in the case of financial prediction, the application of the ML techniques in the case of the Egyptian stock market and the MENA stock markets in general has remained low. According to the World Development Indicators data published by the World Bank in 2025, the global stock market capitalization has grown to 114% of the world GDP in 2007 from merely 27% in 1975. However, the financial crises that followed led to a decline in the stock market capitalization in the following years, and it reached merely 94% in 2014. However, it is expected to reach the figure of $128.07 trillion, which is about 130% of the world GDP, in the year 2025. In the case of the Egyptian stock market, the focus will be on the performance evaluation in the period ranging from 2000 to 2023. As depicted in Figure 1, the stock market capitalization reached a peak in the year 2007 when it reached 107% of the GDP, as opposed to merely 87% in the previous year. However, it declined drastically in the following year due to the global financial crisis. It has reached merely 11% in the year 2024. The major factors that have led to the performance in the stock market are the global financial crisis that led to a fall in the EGX30 index by more than half, the revolution in the year 2011 that led to political instability in the country, the floatation of the Egyptian pound in the year 2016, the COVID-19 pandemic, and the Russia-Ukraine war that led to a surge in the prices of essential commodities, thus affecting the inflation rates in the country.

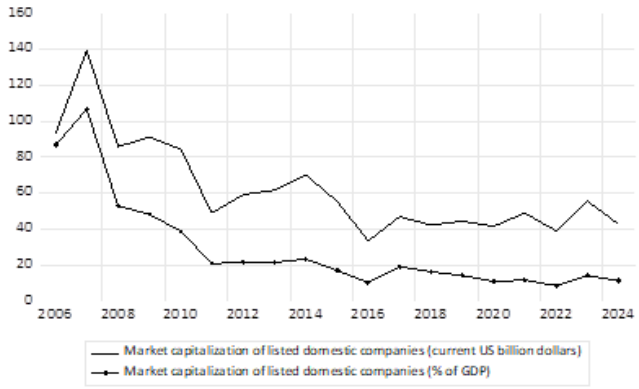

Figure 1: Capitalization of Egypt's Market for Listed Domestic Companies.
Source: WDI Database, World Bank (2025)

This study bridges the gap by using a comparative approach with six different ML techniques, namely Random Forest, SVM, Logistic Regression, Naive Bayes, KNN, and Gradient Boosting, using the annual stock market performance of Egypt over a period of 24 years, along with 13 different macroeconomic variables. Further, a neural network model has been used to determine the best accuracy level of prediction as well as the extent of influence of each predictor variable using the parameter estimation method. The period of analysis, from 2000 to 2023, has witnessed the entire gamut of structural, political, and financial changes that have impacted the Egyptian stock exchange, making it an ideal period to identify the robustness of the variables that have impacted the stock market during the period of crisis as well.

1.1 Scope and Significance

The present study's coverage includes the comparative evaluation of the ML algorithms' performance in forecasting stock returns, as well as the feature attribution analysis to generate relevant insights into the relative importance of the macroeconomic indicators on the stock market movement in Egypt. The relevance of the present study is evident on three fronts: Firstly, the present study offers the first comparative ML-based evaluation of the determinants of the Egyptian stock market movement from 2000 to 2023, which covers an unprecedented period of unprecedented macroeconomic and political shocks. Secondly, the present study offers the first ML-based evidence of the relative performance of neural networks vis-à-vis traditional ML classifiers on the stock market movement in the Egyptian context, which adds to the burgeoning literature on the applications of ML algorithms in the analysis of the dynamics of the financial market movement (Khan et al., 2024; Sajor, Ulla, & Pizzaro-Uy, 2023). Thirdly, the results of the present feature importance analysis provide policymakers with a precise hierarchy of the macroeconomic indicators that need to be monitored to prevent speculative bubbles in the Egyptian stock market movement, which would be of direct relevance to the Central Bank of Egypt, the Financial Regulatory Authority, and the Ministry of Finance of the country. The rest of the paper is arranged as follows: Section 2 offers a review of the theoretical and empirical literature on the macroeconomic determinants of the stock market movement; Section 3 offers the research objectives; Section 4 offers the data, variables, and methodology; Section 5 offers the results and their discussion; and Section 6 offers the policy recommendations, implications, and concluding remarks of the present study.

1.2 Research Objectives

Aligned with the three-dimensional framework of the empirical findings, this study establishes three research objectives, each corresponding to a distinct aspect of the results:

- To perform a comparative evaluation of six supervised ML classification algorithms—Random Forest, SVM, Logistic Regression, Naive Bayes, KNN, and Gradient Boosting—in forecasting Egyptian stock market returns over the period 2000–2023.
- To identify and rank the relative significance of 13 macroeconomic predictor variables in influencing stock market returns in Egypt, based on feature importance scores derived from the best-performing ML model.
- To measure the directional and magnitude-weighted contribution of each macroeconomic variable to the stock price index through parameter estimation within the neural network.

2. Literature Review

The theoretical basis of the macroeconomic factors influencing stock prices can be traced back to the discounted cash flow (DCF) model, which holds that the intrinsic value of stocks equates to the present value of all expected future cash flows discounted at a risk-adjusted rate (Asravor & Fonu, 2021). In such a framework, any macroeconomic factor that influences investors' perceptions of future earnings, discount rates, and risk will ultimately influence stock prices. In terms of empirical evidence, such a theoretical framework has been implemented through a plethora of different variables, broadly categorized into real macroeconomic factors such as GDP and industrial production, and financial-monetary factors such as interest rates, money supply, and exchange rates (Khan et al., 2024; Sajor et al., 2023; Verma & Bansal, 2021).

2.1 Gross Domestic Product

Gross domestic product (GDP) is the most direct measure of macroeconomic output and serves as the fundamental driver of business profitability, investor sentiment, and stock market performance. The theoretical basis of this relationship is that an expanding GDP fuels aggregate demand, boosts business profitability, increases dividends, and pushes up stock prices, while a declining GDP fuels recession, business losses, and declining stock prices. Empirical evidence also confirms the positive relationship between GDP and stock market performance. Islam et al. (2023) found that there was a statistically significant long-run co-integration relationship between GDP growth and returns on the Dhaka Stock Exchange in Bangladesh, which confirms that GDP growth exerts upward pressure on stock market performance. Similarly, Idan (2022) found that GDP dynamics dominate the Iraq Stock Exchange, where oil-related GDP dynamics were the primary determinant of stock market performance in Iraq. Kengatharan & Vanajah (2021) also found that stock market development and economic growth were mutually reinforcing forces in Sri Lanka, particularly in the long run. This finding is consistent with the theoretical underpinning of Tobin's q theory, which confirms that economic output fuels upswings in market values of firms, which rise above replacement costs, leading to further stock market upswings. In the present study, GDP has been given prominence as a predictor of stock market

performance on account of the dominance of cyclical industries like tourism, remittances, and hydrocarbons, which contribute to volatility in the Egyptian economy and, in turn, to the low performance of the Egyptian stock market.

2.2 Interest Rates

There are several interest rate effects on stock prices. These include the discount rate effect, corporate finance effect, and portfolio balance effect. The discount rate effect works through the DCF model. An increase in interest rates by the Central Bank of the country leads to an increase in the discount rates used in the DCF model. Consequently, the present value of stocks decreases. The corporate finance effect works through the interest rates used to pay debt. An increase in interest rates leads to an increase in the cost of debt repayment. Consequently, the profit margin and hence the dividends paid out to shareholders decrease (Abor & Bokpin, 2010). The portfolio balance effect works through the relative attractiveness of stocks and bonds. An increase in interest rates leads to the relative attractiveness of bonds over stocks. Consequently, the demand for stocks decreases, leading to a fall in their prices. Alzoubi (2022) provides empirical evidence of the negative relationship between interest rates and stock prices. The study finds that there is a negative relationship between interest rates and the stock prices of the banking sector across different countries. Moreover, the study finds that the stock prices of regulated industries such as utilities, real estate, and telecommunication services decrease with an increase in interest rates. In addition, the study finds that monetary policy shocks have a significant impact on stocks and bonds. An anticipated increase in interest rates has a correlated effect on stocks and bonds. This is important to the underdeveloped multi-asset market structure of Egypt.

2.3 Inflation

The relationship between inflation and stock returns is theoretically uncertain and empirically debatable. Based on the Fisher hypothesis, stocks act as an inflation hedge such that the nominal corporate revenues increase proportionally with the inflation rate. Consequently, the real stock returns remain unchanged. However, empirical studies have provided evidence against the Fisher hypothesis by showing the negative relationship between inflation and stock returns. High inflation leads to tighter monetary policy, which increases the discount rates (Chiang, 2024). High inflation also leads to a reduction in the purchasing power of the public and consequently corporate revenues. In addition, inflation increases the risk premium demanded by investors (Esen, Yıldırım, & Akyurt, 2025). Thorbecke (2025) found the relationship between inflation and stock returns to be highly negative in the United States during the tightening period after the COVID-19 crisis. The study attributed the findings to the aggressive increase in interest rates by the Federal Reserve. Similar findings were obtained for the banking stocks in the emerging economies due to the impact of high inflation. Abid (2025) extended the study to the impact of inflation surprises and tightening by the Federal Reserve on the stock market in the United States. The study found threshold effects between inflation and stock returns.

2.4 Exchange Rates

The relationship between the stock markets and the exchange rates is theoretically two-fold and complex. The classical model based on the flow-oriented approach implies a positive relationship between the stock markets and the exchange rates. The depreciation of the domestic currency would enhance the export competitiveness and increase the revenues earned by the export-oriented companies in foreign currency units, hence positively affecting the stock prices. On the other hand, the portfolio balance model implies a negative relationship between the stock markets and the exchange rates. The appreciation in the stock prices would attract foreign investment in the domestic assets, hence appreciating the domestic currency. Similarly, Verma & Bansal (2021) undertook a systematic study based on the findings of 38 research papers on the interactions between the stock markets and the exchange rates. The study concluded that the nature of the relationship between the stock markets and the exchange rates depends on the economic structure, trade policies, and the monetary policy regime in the specific country. The import-dependent emerging economies are likely to show a negative correlation between the currency fluctuations and the stock market performance. Egypt, as a net importer of food, energy, and capital goods, is likely to show a negative correlation between the depreciation of the Egyptian pound and the stock prices, hence a negative impact on the stock prices in accordance with the findings on the neural network parameter estimate of 0.433 on the exchange rates obtained in the present study (Gadou, 2015).

2.5 Money Supply

Money supply is one of the most researched macroeconomic variables influencing stock markets, and its impact is explained by various transmission channels as well. The liquidity channel suggests that an increase in monetary expansion adds more investable funds, which in turn increases the demand for stocks, causing stock prices to appreciate (Liu & Clarkson, 2025). The interest rate channel suggests that an increase in money supply, via the traditional Keynesian liquidity preference relationship, reduces interest rates, which in turn reduces the discount rate, increasing the present value of expected equity cash flows. Additionally, an expansion in money supply, via Tobin's q model, suggests that stock prices appreciate to levels higher than the capital replacement costs, thereby inducing investment. Recent literature has focused on the portfolio allocation channel of money supply in influencing equity markets, highlighting the empirical findings of developed economies regarding the impact of quantitative easing on stock markets. Gómez-Cram & Grotteria (2022) have shown, via a real-time analysis of the communication of the Federal Reserve, that the signals regarding the direction of money supply are rapidly incorporated into stock prices. In the context of the Indian stock market, unanticipated monetary expansions result in positive stock return surprises, whereas anticipated monetary expansions have already been factored into the stock market. Unexpected monetary shocks dominate the impact of money supply on stock markets in the G20 countries, influencing both developed and emerging markets. Consistent with these findings, the neural network parameter estimates of the present study reveal money supply as the single largest contributor to the hidden neuron (0.520), which suggests that the stock market performance in Egypt is highly sensitive to money supply, thereby reasserting the critical importance of the monetary policy stance of the Central Bank of Egypt on investor sentiment (Kashyap & Stein, 2023).

2.6 Oil Prices

The relationship between crude oil prices and stock market returns has a well-established theoretical basis, albeit an empirically context-dependent relationship depending on the economic structure of the concerned country. In the case of oil-importing countries such as Egypt, an increase in oil prices translates into a negative terms of trade, higher production costs in oil-intensive sectors, squeezed corporate profitability, higher inflation, and, consequently, lower stock market returns (Agwu & Haydar, 2023). This effect also indirectly works through the monetary channel, as the inflationary pressures emanating from oil price hikes might prompt the central bank to raise interest rates, further negatively affecting stock market returns. Alamgir & Amin (2021) have empirically confirmed the same effect in the case of South Asian emerging markets, wherein an increase in oil prices led to a decline in the value of the local currencies, higher inflation, and a considerable negative effect on the stock markets of these countries. The recent phenomenon of the 'financialization of commodity markets' adds a new dimension to the relationship, wherein oil price shocks, as well as stock market shocks, might be directly correlated through the common presence of oil futures and stock exchange derivatives in the investment portfolios of the same set of institutional investors (Bhowmik & Wang, 2020). Being an oil-importing country, despite its limited oil production, Egypt remains highly susceptible to oil price shocks, as was the case in the recent Russia-Ukraine conflict-driven oil price hike in 2022, which led to a surge in inflation and negatively impacted the country's balance of trade.

2.7 Gold Prices

Traditionally, gold is an effective safe-haven instrument as well as an inflation hedge. The relationship between gold prices and stock markets is fundamentally competitive in nature. If the stock market is risky or if inflationary pressures increase, it is quite obvious that the investor would divert his funds from the stock market to gold. This would establish a negative correlation between gold prices and stock markets. Joseph & Rajeshwari (2023) have also analyzed the relationship between gold prices and sectoral stock indices on the Bombay Stock Exchange in India. The authors have confirmed statistically significant negative correlations between gold prices and stock markets for all sectors. This negative correlation is also theoretically consistent with portfolio theory, as gold prices and stock markets compete as effective portfolio instruments for wealth allocation purposes. In this study, the parameter estimates of the neural network model assigned a weight of 0.520 for gold prices in the hidden layer, which is equal in value to the money supply and the highest value for any predictor variable. This establishes the fact that fluctuations in gold prices have a major influence on the dynamics of the Egyptian stock market index. Gold is not only an effective hedge in the Egyptian investment environment but also a leading indicator for the Egyptian stock markets, as it is an essential component of the cultural heritage of the people of this country as a store of wealth for both individuals as well as institutions.

2.8 Foreign Direct Investment

Foreign direct investment affects stock market performance in several theoretical dimensions, such as capital deepening, liquidity, participation, and technology/knowledge spillovers that enhance the productivity of corporations and hence the stock market as a whole (Chizema, 2025; Ghulam et al., 2025). Neoclassical growth theory explains that FDI into a host country boosts the marginal product of capital in the host country, hence encouraging investment and growth in corporations. However, the empirical results show that the effectiveness and magnitude of FDI on stock markets are conditional on institutional quality, while the sectoral composition of FDI affects its impact on stock markets. Chizema (2025) showed that the benefits that FDI accords to capital markets in South and Southeast Asia critically depend on the capacity of the host country's institutions to transmit the spillover effects of FDI on the stock market. FDI in Egypt has concentrated in the hydrocarbons sector and real estate, as opposed to the manufacturing sector and high-tech industries, which may negatively affect the stock market. This is in line with the results obtained in the current study using the neural network model, in which FDI has a feature importance score of merely 2%.

2.9 Financial Market Uncertainty

Industrial production and employment, and financial market uncertainty, which is often captured through asset price volatility indices like the VIX, are widely documented determinants of stock returns. Bhowmik & Wang (2020) provide a systematic review of the extant literature on stock market volatility and returns, which concluded that financial market uncertainty always depresses stock market valuations through a variety of mechanisms. For instance, increased levels of financial market uncertainty lead to an increase in the risk premia that investors demand, which results in precautionary disinvestment and savings, and creates self-reinforcing mechanisms of negative feedback through margin calls and stop-loss orders. Sarwar (2023) showed that the relationship between stock and bond market returns becomes significantly more negative during periods of high levels of financial market uncertainty, which captures the flight to safety phenomenon. Industrial production is a widely used leading indicator of economic and corporate output, where an increase in industrial production is indicative of rising corporate fundamentals and hence rising stock prices, and vice versa.

2.10 Employment

The relationship between employment and stock prices is theoretically uncertain. An increase in employment can imply economic growth, but it can also imply an increase in interest rates by the Central Bank, which can lead to a decrease in stock prices (Ring, 2023). In the present study, the feature importance scores for industrial production (0.8%), employment (0%), and financial market uncertainty (6.5%) imply that these factors are overshadowed by the dominant factors in the structural context of Egypt.

2.11 Goods and Services Tax and Foreign Currency Reserves

The effect of the implementation of value-added taxation (VAT/GST) on the stock market is seen through the business cycle effect and the efficiency effect. In the study on the GST effect on the Indian stock market indices before and after the GST was implemented, Seok, Cho, & Ryu (2024) found that the GST had a mixed effect on the Indian stock market indices, where the GST reduced the volatility of certain sectoral indices due to improved tax administration and reduced market

distortions, but the GST also had a negative effect on certain sectoral indices due to increased compliance costs and reduced profit margins. In the Indian automotive sector, Kamat & Sen (2024) found that the GST had no significant effect on the net profits of the automotive sector due to the pass-through effect of the GST on the firms' fiscal shocks. In the case of the Egyptian VAT, the feature importance score of the marginal effect of VAT on the stock market is 0.1%.

2.12 Foreign Currency Reserves

Foreign currency reserves, though theoretically of considerable importance as indicators of the external balance, have shown negligible predictive ability regarding the stock market, with a feature importance of merely 0.1% in the present analysis. This indicates that at the annual frequency of analysis, the behavior of foreign exchange reserves appears to be driven by macroeconomic factors to a large extent. These findings, therefore, indicate the presence of a hierarchical structure wherein the behavioral, monetary, and commodity-related variables assume the central position in influencing the stock market behavior in Egypt, whereas the structural and fiscal variables remain relegated to a secondary position.

3. Data, Methodology and Empirical Results

3.1 Data and Study Variables

The empirical analysis is based on annual data from 2000 to 2023. This covers a total of 23 annual observations. The time period covers the complete business cycle of the Egyptian stock market under the liberalisation process. This includes the pre-crisis expansion period from 2000 to 2007, the global financial crisis period from 2008 to 2009, the Arab Spring period from 2010 to 2014, the structural adjustment episode of floating the Egyptian pound from 2015 to 2017, and the combined effects of the coronavirus pandemic and geopolitical tensions from 2020 to 2023. Annual data for all variables is obtained from the United Nations Conference on Trade and Development statistical database, the World Bank's WDI database, official records from the Egyptian stock exchange, and reports from the Central Bank of Egypt. The dependent variable is the EGX30 stock prices' annual return, which is classified as a binary variable for positive/negative annual returns. This is required for the application of classification-based ML algorithms. The list of variables used in this study along with their acronyms and theoretical classifications is provided in Table 1.

Table 1: Study Variables: Definitions, Acronyms, and Theoretical Classification.

Variable	Acronym	Category	Expected Direction
Inflation Rate	INF	Financial-Monetary	Negative
Interest Rate	IR	Financial-Monetary	Negative
Exchange Rate	ER	Financial-Monetary	Ambiguous
Money Supply	MS	Financial-Monetary	Positive
Crude Oil Price	VOL	Commodity	Negative
Gross Domestic Product	GDP	Real-Economic	Positive
Industrial Production	IP	Real-Economic	Positive
Foreign Direct Investment	FDI	External Capital	Positive
Gold Price	GP	Commodity	Negative
Goods and Services Tax	GST	Fiscal	Ambiguous
Foreign Currency Reserves	FCR	External Balance	Positive
Financial Market Uncertainty	FMU	Market Sentiment	Negative
Stock Price — Lagged Values	SpF	Behavioural / Momentum	Positive (Momentum)

Note All data obtained from UNCTAD and World Development Indicators (WDI) databases, the World Bank, Egyptian Exchange official records, and the Central Bank of Egypt reports. Source: Authors.

3.2 Machine Learning Algorithms and Mathematical Formulation

The study adopts a two-phase analytical framework. Phase I involves benchmarking six supervised ML classification algorithms to evaluate their predictive performance on annual stock market returns in Egypt. In Phase II, the best-performing model is used to derive feature importance scores, followed by the application of a MLP neural network to obtain interpretable parameter estimates. All models were implemented in Python using the Scikit-learn library. The mathematical formulations underlying the six classification algorithms and the neural network are provided below.

3.2.1 Random Forest (RF)

Random Forest is an ensemble technique based on bagging, which builds a large collection of decision trees using bootstrapped samples of the training dataset. Predictions from these trees are then combined through a majority vote for classification purposes. During model initialization, the squared-error loss is minimised with respect to the constant prediction γ (Metin, 2025):

$$F_0(x) = \frac{1}{n}\sum_{i=1}^{n} (y_i - \gamma)^2, \quad (1)$$

In this formulation, y_i represents the observed target value for the i-th observation, γ denotes the expected (constant) prediction, and n is the total number of training observations. Each decision tree is trained on a distinct bootstrap sample, and at each split node, a random subset of features is considered, which reduces variance by decorrelating the trees. The final classification is obtained through a plurality vote across all trees.

3.2.2 Support Vector Machine (SVM)

SVM is a maximum-margin supervised classifier that projects input features into a high-dimensional kernel-induced space and identifies the hyperplane that optimally separates the two binary classes. The underlying optimization is convex, ensuring a globally optimal solution. Rochim, Widyaningrum, & Eridani (2021) extended SVM to non-parametric regression via a loss-minimizing approach that maintains the flatness of the decision surface. For classification, SVM addresses the following primal optimization problem: it maximizes the margin $2/\|w\|$ subject to the constraint $y_i(w \cdot x_i + b) \geq 1$, with kernel functions—linear, polynomial, or radial basis function—allowing the separation of classes that are not

linearly separable in the original feature space.

3.2.3 Logistic Regression

Logistic regression estimates the posterior probability of a binary outcome by applying a sigmoid transformation to a linear combination of predictor variables (Joshi & Dhakal, 2021). The general formulation is:

$$log_e L(\beta) = \sum_{i=1}^{n} Y_i(X_i'\beta) - \sum_{i=1}^{n} log_e[1 + exp(X_i'\beta)] \quad (2)$$

This represents the log-likelihood function for a binary logistic regression model. The first summation assigns higher likelihood to parameter vectors ß that accurately predict the observed outcomes Yi through the linear predictor Xi'ß. The second summation imposes a penalty on ß via log(1 + exp(Xi'ß)), ensuring that the predicted probabilities remain constrained between 0 and 1.

3.2.4 Naïve Bayes

Naïve Bayes is a probabilistic classifier based on Bayes' theorem. It operates on the principle of conditional independence. Given the class label, all the values of the features are independent of each other (Nguyen et al., 2025). Though the independence assumption is violated in the case of macroeconomic data due to the correlation between the variables, Naïve Bayes is computationally efficient and works well in high-dimensional data.

3.2.5 K-Nearest Neighbours (KNN)

KNN is a non-parametric, instance-based learning algorithm that assigns a class to an unseen observation based on a majority vote of its k closest neighbours in the training dataset (Kang, 2021). The proximity of neighbours is calculated using the Minkowski distance metric, which generalizes both the Euclidean and Manhattan distance measures:

$$\|\mathbf{x}' - \mathbf{x}_j\|^p = \left(\sum_{i=1}^{q} \left| (x_i)' - (x_i)_j \right|^p \right)^{1/p} \quad (3)$$

When p = 2, the Minkowski distance reduces to the Euclidean distance. Depending on the nature of the data space, alternative distance measures may be more appropriate, such as the Hamming distance in B^q.

3.2.6 Gradient Boosting (GB)

Gradient Boosting is a sequential ensemble technique that builds an additive model by iteratively fitting weak learners to the pseudo-residuals of the existing ensemble (Sibindi et al., 2023). The model is updated recursively according to the following rule:

$$F_{\mathrm{m}}(\mathrm{x}) = F_{\mathrm{m-1}}(\mathrm{x}) + \mathrm{v}\Delta_{\mathrm{m}}(x), \quad (4)$$

In this formulation, Fm(x) represents the updated model for the input x, while Fm-1(x) denotes the preceding model. The term Δm(x) corresponds to the weak learner fitted at iteration m, and v is the shrinkage (or learning rate) parameter controlling the contribution of each learner.

3.2.7 Multilayer Perceptron Neural Network

Following the Phase I benchmarking of the six ML classifiers, a MLP neural network is implemented in Phase II to perform feature attribution and parameter estimation. The MLP architecture consists of an input layer that receives the 13 macroeconomic predictors, a single hidden layer containing one neuron H(1:1) with a sigmoid activation function, and an output layer that predicts the stock price index (SPI). The general formulation of the neural network is:

$$\boldsymbol{Y_t = f(H_1X_{t-1}, H_2X_{t-2}, \ldots, H_nX_{t-n}) + u} \quad (5)$$

In this formulation, Y_t represents the output layer, corresponding to the stock market return in period t. X_1, X_2, …, X_n denote the input layer variables, representing the 13 macroeconomic predictors. H_1, H_2, …, H_n are the weights of the hidden layer, capturing the learned contribution of each lagged input. The function f is the hidden layer activation function (sigmoid), and u represents the error term. The network was trained using the MLP procedure in SPSS v.22, with a single hidden layer and one output neuron, and convergence was determined by a stopping rule of one consecutive step with no reduction in training error. Table 4 details the training-testing data split, while Table 5 provides the model convergence statistics.

4. Empirical Results and Discussion

4.1 Phase I: Machine Learning Algorithm Performance Benchmarking

A summary of the relative performance of the six ML classifiers on the five-evaluation metrics of AUC, classification accuracy (CA), F1 score, precision, and recall is provided in Table 2. The MLP neural network model has the highest performance on all five metrics: AUC = 0.872, F1 score = 0.711, recall = 0.755, and classification accuracy = 0.710, confirming the superiority of the non-linear model to capture the non-linear and asymmetric determinants of Egyptian stock market returns. The fact that the non-linear model outperforms all the linear models, including Logistic Regression (AUC = 0.712), is theoretically significant and confirms that the dynamics of the Egyptian equity market cannot be captured using linear decision boundaries and that non-linear models that allow for the incorporation of complex interactions are necessary to model the market returns. Gradient Boosting follows the MLP model on the basis of the AUC score = 0.820, which reflects the model's capacity to incorporate complex non-linear patterns through sequential learning. KNN, Naive Bayes, and SVM have intermediate relative performance on the five metrics, with AUC = 0.721, 0.728, and 0.752, respectively. Random Forest underperforms relative to Gradient Boosting on the basis of the AUC score = 0.728, despite the similarity in the model structure, which is based on ensemble methods, due to the fact that Gradient Boosting minimizes bias through sequential learning, while Random Forest minimizes variance through bagging.

Table 2: Comparative Performance of Machine Learning Classification Algorithms for Egyptian Stock Market Return Prediction (2000–2023).

Algorithm	AUC	CA	F1-Score	Precision	Recall
Gradient Boosting (GB)	0.820	0.700	0.701	0.703	0.710
K-Nearest Neighbors (KNN)	0.721	0.690	0.679	0.699	0.689
Logistic Regression	0.712	0.681	0.685	0.683	0.699

Naïve Bayes	0.728	0.621	0.672	0.645	0.649
Neural Network (MLP)	0.872	0.710	0.711	0.726	0.755
Random Forest	0.728	0.648	0.652	0.655	0.659
Support Vector Machine (SVM)	0.752	0.651	0.643	0.646	0.658

Note: AUC = Area Under the Receiver Operating Characteristic Curve; CA = Classification Accuracy; F1 = Harmonic mean of Precision and Recall. Neural Network (MLP) has the highest AUC and precision among all the algorithms, which validates the choice of this model as the best model to be used in the analysis in Phase II. Source: Python (Scikit-learn) results compiled by the authors.

4.2 Phase II: Feature Importance Analysis

Once the MLP neural network was determined to be the most accurate predictive model, Phase II makes use of it to calculate the feature importance scores, which are a quantification of each individual variable's contribution to the overall predictive capability of the model. Ranked feature importance scores of all 13 macroeconomic predictors are given in Table 3.

Table 3: Feature Importance Scores for Egyptian Stock Market Determinants — Neural Network Model (2000–2023).

Predictor Variable	Importance Score (%)	Rank
Stock Price — Lagged Values (SpF)	18.0	1st
Gross Domestic Product (GDP)	13.2	2nd
Gold Price (GP)	13.0	3rd
Crude Oil Price (VOL)	12.3	4th
Exchange Rate (ER)	9.5	5th
Inflation Rate (INF)	8.5	6th
Interest Rate (IR)	8.0	7th
Money Supply (MS)	8.0	7th
Financial Market Uncertainty (FMU)	6.5	9th
Foreign Direct Investment (FDI)	2.0	10th
Industrial Production (IP)	0.8	11th
Goods and Services Tax (GST)	0.1	12th
Foreign Currency Reserves (FCR)	0.1	12th
Employment (EM)	0.0	14th

Note: Feature importance scores represent the proportional contribution of each predictor to the neural network model's predictive accuracy. The scores add up to 100%. Predictors with feature importance scores less than 1% have negligible predictive contribution and can be safely omitted from parsimonious model refinements. Source: Python (Scikit-learn) results.

Based on the results of the feature importance analysis, three theoretically significant results emerge. Firstly, the fact that lagged stock price ranks the highest (18%) among all the predictors suggests that momentum effects and self-fulfilling expectations dominate the Egyptian equity market, rather than macroeconomic fundamentals. This is consistent with the theoretical predictions of Keynes' animal spirits and the behavioural finance literature (Agarwal et al., 2025; Nguyen et al., 2025). Secondly, the fact that the feature importance of commodity prices, like gold (13%) and crude oil (12.3%), is higher than that of financial-monetary indicators like exchange rate (9.5%), inflation (8.5%), interest rate (8%), and money supply (8%) suggests that the Egyptian equity market is significantly impacted by global commodity prices. This is a structural vulnerability of the Egyptian economy, given its dual role as an oil-importing country. Thirdly, the fact that the feature importance of employment, GST, and foreign currency reserves is very low or near zero suggests that these indicators do not add any additional information to the predictions of the dominant factors.

4.3 Neural Network Case Processing and Model Convergence

The MLP neural network model was trained and tested using the 23-year dataset from 2000 to 2023. Table 4 presents the case processing summary, which reflects the training and testing proportions of 86.9% and 13.1%, respectively. It is observed that the training set is comprised of 20 annual observations from 2000 to 2019, and the test set is comprised of 3 observations from 2020 to 2022. The out-of-sample test of the model is conducted on the latter period, which reflects the most structurally turbulent events such as the COVID-19 shock and the initial period of the Russia-Ukraine-driven commodity crisis in 2022.

Table 4: Case Processing Summary — Multilayer Perceptron Neural Network (MLP).

	Sample	N	Percent
Sample	Training	20	86.9%
	Testing	3	13.1%
Valid		23	100%
Excluded		0	—
Total		23	—

Note: The 86.9%/13.1% split is standard practice for small-N time-series ML applications. The test sample includes the structurally unusual COVID-19 and geopolitical shock years 2020-2022, thus providing a stringent out-of-sample test benchmark. Source: SPSS v.22 output.

Table 5 shows the model convergence statistics for the training and testing phases. From the statistics, it is evident that the training sum of squares error (SSE) is 0.651, while the relative error is 0.092. On the other hand, the testing SSE is 0.168, while the relative error is 0.081. The fact that there is a 91% reduction in the error from the naive baseline to the trained model clearly shows that the model learned effectively in the training phase. Moreover, the fact that the error in the testing data is slightly lower than the error in the training data, and not significantly higher, shows that the model learned effectively without any sign of overfitting. The fact that convergence occurred in a single step without

any increase in error clearly shows that the weights were optimized effectively. Moreover, the fact that the error did not increase in the next step clearly shows that the weights were optimized quickly and effectively. The fact that the model stopped after a single step when there was no reduction in error clearly shows that the model did not suffer from any sign of over-training, as the final weight matrix will represent the true signal and not the idiosyncratic noise in the training data.

Table 5: Multilayer Perceptron Neural Network Model Summary — Training and Testing Phase Statistics.

Phase	Statistic	Value
Training	Sum of Squares Error (SSE)	0.651
	Relative Error	0.092
	Stopping Rule Used	1 consecutive step with no decrease in training error
	Training Time	00:00:00.013 (milliseconds)
Testing	Sum of Squares Error (SSE)	0.168
	Relative Error	0.081

Note: The relative error value in the testing phase (0.081) is marginally lower than in training (0.092), indicating the absence of overfitting. Error computations in the testing phase are based exclusively on the 3-observation holdout sample. The neural network reduces total prediction error by approximately 91% relative to a naïve constant predictor. Source: SPSS v.22 output.

4.4 Neural Network Parameter Estimates and Directional Analysis

Table 6 presents the full weight matrix of the trained MLP neural network, including the input-to-hidden layer weights for the 13 macroeconomic predictors along with the associated bias terms, as well as the hidden-to-output layer weight. These parameter estimates capture both the direction and magnitude of each predictor's contribution to the activation of the hidden neuron, and consequently, to the prediction of the SPI within the nonlinear neural network framework. The parameter estimates presented in Table 6 offer analytically rich insights into the directional and magnitude-weighted influence of each macroeconomic variable within the MLP neural network's learned representation. Money supply and gold price possess the largest absolute weights in the input layer, identical in magnitude, indicating that they are the two strongest suppressors of the hidden neuron.

The negative relationship between the money supply and the hidden neuron may seem paradoxical; however, this phenomenon reflects the monetary conditions of Egypt, where sudden increases in the money supply have historically preceded the onset of inflation that negatively impacted the returns of equity investments and risk-adverse investor behaviour, leading to a cumulative adverse effect on stock returns. The exchange rate ranks third, which aligns with the theoretical predictions of the effect of the depreciation of the Egyptian pound, which has frequently featured in the macroeconomic history of Egypt, on import costs, inflation acceleration, and profit margins of companies. The crude oil price and VAT/GST feature importance rankings of the fourth position in the model, which confirms the role of the oil price effect and increased VAT/GST burdens as suppressors of equity returns in Egypt. On the stimulatory side of the model, the hidden neuron is positively impacted by FDI (+0.210), industrial production (+0.176), and lagged stock price (+0.153). The lagged stock price parameter weight and feature importance of 18% (refer to Table 3) validate the behavioural momentum hypothesis that the Egyptian equity market is significantly impacted by the price movement of the preceding day, leading to self-referential investor behaviour that aligns with the animal spirits hypothesis (Agarwal et al., 2025). Moreover, the feature importance of GDP ranks second, while the parameter weight is +0.045, and the feature importance of foreign currency reserves ranks sixth while the parameter weight is +0.012. This phenomenon may seem paradoxical; however, the parameter weights reflect directional influences on the model, whereas feature importance reflects the overall contribution of the feature to the model output, which may be subject to non-linear effects of the GDP on the model output that provide overall predictive power to the model without a significant directional effect. The hidden neuron output layer weighs +0.719, which reflects that after the overall inputs to the model are processed through the sigmoid activation function of the hidden neuron layer, the overall inputs have a strong positive leverage effect on the predicted stock price index output of the model.

Table 6: Multilayer Perceptron Neural Network Parameter Estimates — Input Layer to Hidden Layer (H (1:1)) and Hidden Layer to Output Layer (SPI).

Layer	Predictor / Neuron	Weight → Hidden H (1:1)	Weight → Output SPI
Input Layer	Bias	−0.453	—
	Inflation Rate (INF)	−0.017	—
	Interest Rate (IR)	−0.181	—
	Exchange Rate (ER)	−0.433	—
	Money Supply (MS)	−0.520	—
	Crude Oil Price (VOL)	−0.357	—
	Gross Domestic Product (GDP)	+0.045	—
	Industrial Production (IP)	+0.176	—
	Foreign Direct Investment (FDI)	+0.210	—
	Gold Price (GP)	−0.520	—
	Goods and Services Tax (GST)	−0.357	—
	Foreign Currency Reserves (FCR)	+0.012	—
	Financial Market Uncertainty (FMU)	−0.106	—
	Stock Price — Lagged Values (SpF)	+0.153	—
	Employment (EM)	+0.015	—

Hidden Layer	Bias	—	−0.189
	H(1:1) — Hidden Neuron Output	—	+0.719

Note that the negative weights in the Hidden Layer column represent the variables that suppress the activation of the hidden neuron signal, i.e., the variables push the hidden neuron signal down. The positive weights in the Hidden Layer column represent the variables that stimulate the hidden neuron signal. The output layer has a weight of +0.719 on the H(1:1) variable, indicating that once the hidden neuron signal is activated, it stimulates the stock price index value. [b] SPI = Stock Price Index. Source: SPSS v.22 output.

5. Conclusion, Recommendations, and Policy Implications

5.1 Summary and Conclusion

This study offers the most comprehensive ML-based analysis of the determinants of the Egyptian stock market to date, using 24 years of annual data from 2000 to 2023 on 13 macroeconomic factors and comparing the relative performance of six supervised learning algorithms to the MLP neural network model. Three key results emerge from the analysis. Firstly, the MLP neural network model far outperforms all the other classifiers on the Egyptian stock market dataset, achieving an AUC of 0.872 and precision of 87.2%, confirming the non-linear and asymmetric nature of the Egyptian equity market. Secondly, the lagged stock price feature is the most significant determinant of the Egyptian stock market, with an importance of 18%, reinforcing the view that behavioural momentum and self-fulfilling prophecies, rather than fundamental factors, dominate the returns on the EGX30 index. Of the fundamental factors, GDP (13.2%), gold price (13%), and crude oil price (12.3%) were the most significant determinants of the Egyptian stock market, while monetary factors like the exchange rate, inflation, interest rate, and money supply combined to account for 34% of the feature importance. Employment, VAT/GST, and foreign currency reserves were found to have negligible effect on the model outcomes. Thirdly, the parameter estimates of the MLP neural network model confirm that money supply and gold price have the strongest suppressive effects on the Egyptian stock market, followed by the exchange rate, reinforcing the view that Egypt is particularly vulnerable to price shocks from the global economy and monetary instability.

5.2 Policy Recommendations

There are a number of important policy implications that can be derived from the results obtained in the previous sections. To start off, the Central Bank of Egypt should implement a real-time market surveillance system that should focus on the following variables: lag price momentum, GDP growth trends, gold price shocks, and crude oil price fluctuations. It should be noted that the combined effect of the aforementioned variables on the prediction of the EGX30 index is more than 56%. It should also be pointed out that the high influence of behavioural expectations calls for the implementation of circuit breakers that can interrupt the self-reinforcing feedback loops that may cause destabilising bubbles in the financial market. Moreover, monetary policy communication should be enhanced. It should be pointed out that the results showed that the money supply has the highest suppressive effect on the prediction of the EGX30 index. It should also be pointed out that the results showed that the pound volatility has the third-highest effect on the prediction of the EGX30 index. Therefore, it can be derived that the management of the exchange rate should be given special attention.

5.3 Implications of the Theory and Future Research

From a theoretical viewpoint, the present study contributes to the theoretical body of knowledge on the determinants of equity markets in emerging economies by showing that the Egyptian stock market does not follow the weak-form Efficient Market Hypothesis, where prices have only 18% predictability, which goes against the Efficient Market Hypothesis assumption of a random walk of prices. The dominance of Keynesian animal spirits over fundamental valuation methods in this emerging market setting further supports the applicability of behavioural finance models, which suggest that rational expectation models may not be appropriate tools for policy-making in the Egyptian case. Future research directions could include the extension of the ML model to monthly or daily frequency data to account for the dynamics of the stock market on a monthly or daily basis, the incorporation of deep learning models to account for the temporal dynamics of the stock market, and the extension of the model to other stock markets of the Middle East and North Africa to check the regional or country-wise applicability of the behavioural-monetary dominance found in the Egyptian case. The methodological framework developed in this study on using comparative ML benchmarking, neural network feature attribution, and parameter interpretation could be used to test the determinants of the stock market in other emerging market settings where data may be scarce.

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