A Machine Learning Framework for Cross-Market Dependency Analysis and Forecasting of Iranian Refinery Stocks

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ABSTRACT

The Iranian stock market is strongly influenced by developments in global energy markets due to the structural dependence of the national economy on oil revenues. This study proposes a machine learning framework for cross-market dependency analysis between global oil market indicators and the stock prices of major Iranian refinery companies listed on the Tehran Stock Exchange. Historical data, including Brent crude oil price, oil trading volume, exchange rate, and temporal variables, were collected and integrated into a unified dataset covering approximately eight years of trading activity. Three machine learning algorithms, including Random Forest Regression, XGBoost Regression, and Polynomial Regression, were evaluated and compared using R^2 score and RMSE metrics. Experimental results demonstrated that the Random Forest model achieved the best predictive performance among the evaluated methods, with R^2 values close to 0.99 for several target stocks. The proposed framework was further validated using out-of-sample market observations collected after the training period. Findings indicate that global oil market variables contain substantial predictive information regarding the behavior of Iranian refinery stocks and can support data-driven investment analysis in energy-dependent financial markets.

Keywords: *Cross-Market Dependency, Machine Learning, Random Forest Regression, Tehran Stock Exchange*

1. *INTRODUCTION*

The stock market plays a pivotal role in economic growth by enabling companies to raise capital and providing investors with opportunities to generate returns [1, 2]. Accurate prediction of stock prices has long been a central challenge in financial research, as it directly affects investment decisions, portfolio management, and risk assessment [3, 4]. The Tehran Stock Exchange (TSE), as the largest capital market in Iran, has attracted considerable attention from both domestic and international researchers seeking to understand its complex dynamics [5, 6, 7].

Iran's economy is heavily dependent on oil revenues, and consequently, the country's economic growth and national income are significantly influenced by global crude oil prices. Despite numerous policy initiatives aimed at reducing this dependency, oil remains a dominant factor in the Iranian economy. As a result, forecasting oil prices has become an important area of research. However, a more practical question for investors and policymakers is how such forecasts can be utilized in stock market decision-making. In this study, we address this gap by employing global oil market indicators and related financial variables to predict the stock prices of four major Iranian refinery companies listed on the Tehran Stock Exchange: Tehran, Tabriz, Isfahan, and Bandar Abbas.

Existing literature on TSE forecasting has explored a wide range of methodologies. Traditional time-series models such as ARIMA have been compared with deep learning approaches including LSTM, RNN, and CNN, with evidence suggesting that deep learning models often outperform linear models in capturing nonlinear market patterns [2]. Other studies have employed artificial neural networks combined with principal component analysis to predict stock prices using accounting variables [3]. In contrast, fuzzy-stochastic data envelopment analysis (DEA) has been applied to evaluate the performance of chemical companies under uncertainty [1]. Recent advances have also incorporated sentiment analysis from social media and

transformer-based models such as RoBERTa to improve TSE index forecasting [5]. Furthermore, alternative studies have examined the effects of corporate water reporting and audit report readability on market efficiency [4, 6]. In the domain of cash flow forecasting, hybrid optimization methods such as Grey Wolf Optimization have been proposed to improve predictive performance [7]. Despite this broad body of research, limited attention has been paid to the use of global oil market indicators—including Brent crude oil prices, Brent trading volume, the USD/IRR exchange rate, and the stock performance of major international oil companies such as Saudi Aramco and Exxon Mobil—for predicting the stock prices of Iranian refinery companies.

This research proposes a machine learning framework for modelling cross-market dependencies between global oil market indicators and Iranian refinery stocks. In the proposed framework, the global market environment—including Brent oil price, trading volume, exchange rate, and temporal variables—acts as an external driver influencing refinery stock prices. Four independent Random Forest regression models are developed to learn the relationship between global market conditions and the stock prices of the target companies. Before selecting the final model, the performance of Random Forest, XGBoost, and polynomial regression models was compared, with Random Forest achieving the highest predictive accuracy ((R^2) up to 0.989).

A key methodological aspect of this study is the temporal alignment of international and domestic market data. Because the New York trading session concludes after the Tehran Stock Exchange closes, information generated in global markets primarily affects the following trading day in Tehran. Therefore, the use of a random train-test split in this study does not introduce significant look-ahead bias, as the explanatory variables originate from a temporally preceding external market environment rather than from future observations of the target market itself.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on stock price prediction, with particular emphasis on studies related to the Tehran Stock Exchange and global commodity markets. Section 3 describes the dataset, feature engineering process, and the proposed modelling framework. Section 4 presents the experimental results, including model comparison and out-of-sample validation. Section 5 discusses the implications and limitations of the findings, and Section 6 concludes the paper and suggests directions for future research.

2. *LITERATURE REVIEW*

Financial market prediction has long been an important research topic because of its implications for investment decision-making, portfolio management, and economic policy [1–3]. In the context of the Tehran Stock Exchange (TSE), researchers have explored various statistical and machine learning approaches to predict stock prices and market indices. Traditional econometric and time-series models such as ARIMA were among the earliest methods applied to financial forecasting problems [2, 15]. However, because financial markets exhibit nonlinear and highly dynamic behaviour, more advanced machine learning and deep learning approaches have gradually gained attention. Studies based on artificial neural networks, principal component analysis, recurrent neural networks (RNN), convolutional neural networks (CNN), and Long Short-Term Memory (LSTM) architectures have reported improved performance compared with classical linear models [2, 3, 5, 15]. In addition, transformer-based sentiment analysis models such as enhanced RoBERTa have recently been integrated with quantitative financial indicators to forecast the TSE index [5].

Despite these reported improvements, several methodological limitations remain common in the literature. One of the most important issues is look-ahead bias, which occurs when future information unintentionally enters the training or evaluation process. Many published studies do not explicitly explain how forward-looking information is prevented during data preparation or train-test splitting procedures [15, 17]. In financial forecasting problems, especially when temporal dependencies exist between markets, failure to address this issue can lead to unrealistically optimistic results. Furthermore, some deep learning models merely learn the persistence behaviour of financial prices, effectively predicting that tomorrow's price will remain close to today's value. Since daily fluctuations in financial markets are often relatively small, particularly in regulated markets such as the TSE, this behaviour may generate apparently high prediction accuracy without providing meaningful predictive capability [10].

Another major challenge concerns dataset size and model applicability. Deep learning architectures such as LSTM, GRU, CNN, and transformer-based networks generally require very large datasets to achieve reliable generalisation performance [15, 20]. However, the Tehran Stock Exchange provides fewer than 4,000 daily observations for most stocks and indices, which is substantially smaller than datasets typically used in studies on developed financial markets. Under such conditions, neural network models are highly susceptible to overfitting and may memorise noise instead of learning robust market dynamics [10]. This limitation is frequently overlooked in studies applying deep learning models to TSE data, raising concerns regarding the reliability of their reported out-of-sample performance.

Because Iran's economy is heavily dependent on oil revenues, crude oil price forecasting has also become an important area of research. Traditional approaches such as Vector Error Correction Models (VECM) and Generalised Autoregressive Conditional Heteroskedasticity (GARCH) models have been widely used to model both long-run relationships and volatility behaviour in oil markets [18]. More recently, hybrid and machine learning-based methods have been proposed to capture nonlinear market structures more effectively. Hybrid frameworks combining decomposition techniques such as TVF-EMD and ICEEMDAN with shallow neural networks or statistical models have shown improved forecasting stability and accuracy [11, 12, 14]. Similarly, GRU-based forecasting systems combined with sub-series clustering and nonlinear feature extraction have demonstrated promising performance in oil price prediction tasks [13, 20]. Other studies have incorporated uncertainty indicators such as the Economic Policy Uncertainty (EPU) index to improve volatility forecasting and analyse the conditional distribution of oil returns [17].

Recent research has also examined cross-market dependency analysis and nonlinear causal relationships between oil markets, stock markets, exchange rates, and other financial variables [17, 20]. In oil-exporting economies, global oil prices can influence domestic stock markets through multiple transmission channels, including exchange rate movements, inflation expectations, and changes in energy-sector valuations. Nevertheless, limited research has specifically investigated these cross-market dependencies in the context of Iranian refinery companies listed on the TSE.

Another emerging direction in the literature involves integrating forecasting systems directly with downstream decision-making and portfolio optimisation objectives instead of focusing exclusively on minimising prediction error [16]. Such approaches aim to improve practical decision quality under uncertainty rather than producing highly precise point forecasts. Additionally, studies examining financial network structures in the TSE have shown that network centrality may function as a systematic risk factor associated with higher expected returns [9].

Overall, the existing literature demonstrates significant progress in financial forecasting and oil price prediction using machine learning and deep learning methods. However, many reported results remain vulnerable to methodological weaknesses such as look-ahead bias, persistence-based forecasting behaviour, and overfitting caused by limited data availability. These limitations are particularly important in the Tehran Stock Exchange, where historical datasets are relatively small and market structure differs substantially from developed financial markets. Therefore, there remains a need for simpler and more robust machine learning frameworks that explicitly address temporal consistency, avoid forward-looking bias, and account for cross-market dependencies between global oil markets and Iranian refinery stocks.

3. *METHODOLOGY*

This study proposes a machine learning framework for analysing cross-market dependencies between global oil market variables and the stock prices of major Iranian refinery companies listed on the Tehran Stock Exchange (TSE). The primary objective is to determine whether international oil market conditions can be used to predict the behaviour of refinery stocks in Iran.

Given the strong dependence of Iran's economy on oil revenues, fluctuations in global oil prices significantly influence exchange rates, industrial profitability, and stock market performance. Accordingly, this research focuses on four major Iranian refinery companies: Tehran Oil Refining Company, Isfahan Oil Refining Company, Tabriz Oil Refining Company, and Bandar Abbas Oil Refining Company, which represent the largest refinery firms in the Iranian capital market.

The modelling framework utilises several global market variables as environmental indicators affecting the target companies. These variables include Brent crude oil price, Brent trading volume, the USD/IRR

exchange rate, and temporal variables extracted from the trading date. In the preliminary stage, additional variables such as the stock prices and trading volumes of Saudi Aramco and Exxon Mobil were also collected and analysed.

The required data were obtained from multiple sources, including the Tehran Stock Exchange Technology Management Company (TSETMC), Google Finance, Yahoo Finance, and the Nobitex exchange platform. The final dataset consisted of 1,645 trading days covering both domestic and international financial markets. The dataset included stock prices of the four refinery companies, Brent crude oil indicators, exchange rate information, and calendar-based temporal features. Examination of the dataset showed no missing values or significant outliers; therefore, no extensive preprocessing procedures were required.

Feature engineering involved extracting both market-based and temporal variables from the dataset. Temporal features included day of year, month, and day of week in order to capture seasonal and periodic trading patterns. A correlation heatmap was then constructed using all numerical variables, including closing prices and trading volumes. The analysis revealed a strong positive correlation between Brent crude oil indicators and the stock prices of major international oil companies. These variables also showed relatively strong correlations with Tehran Oil Refining Company, while correlations with the remaining Iranian refinery companies were moderately weaker.

Because several global oil-related variables exhibited substantial interdependency and overlapping information, the final modelling stage retained Brent crude oil price and Brent trading volume as the primary environmental indicators in order to reduce redundancy and avoid multicollinearity. Consequently, the final feature set used for prediction consisted of Brent crude oil price, Brent trading volume, USD/IRR exchange rate, and calendar-based temporal variables extracted from the trading date.

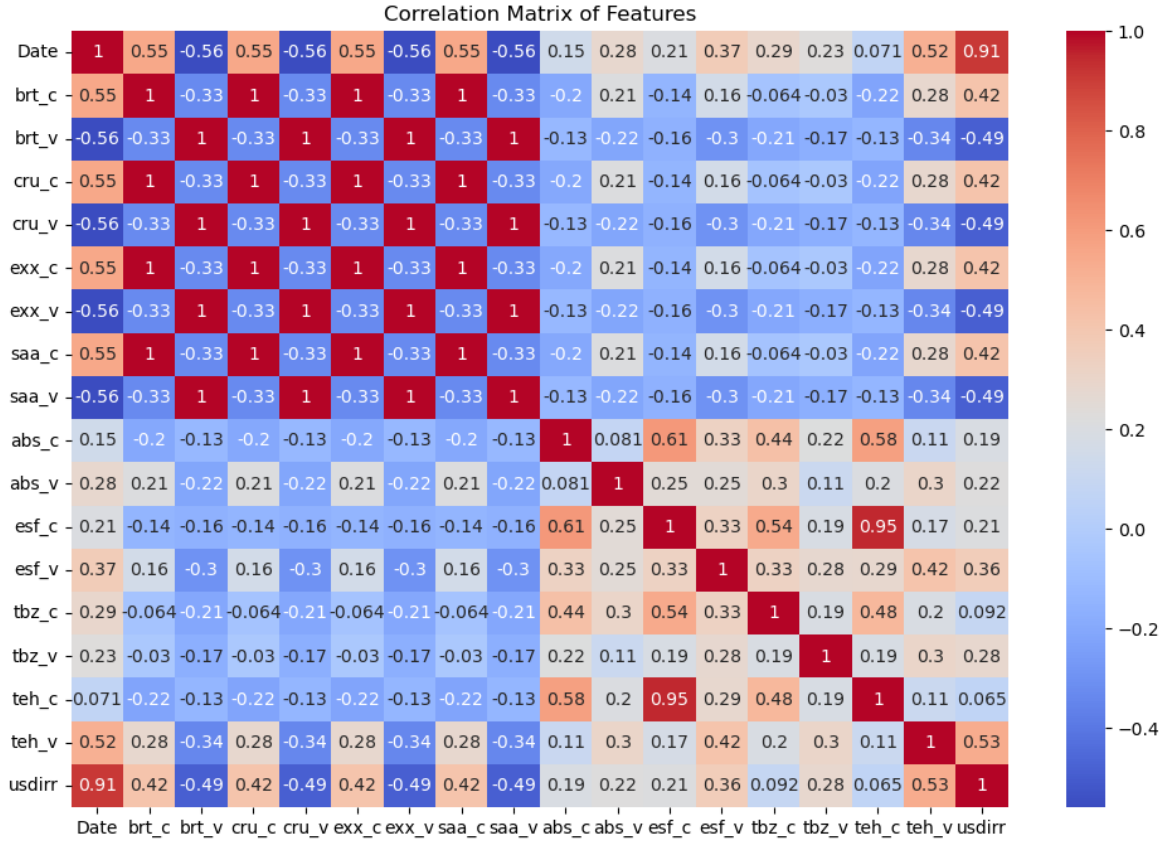

Fig. 1. Correlation Matrix of Features

The conceptual structure of the proposed framework was inspired by a stochastic card game involving a dealer and multiple players. In this analogy, the global market variables act as the "dealer," representing the external environment that influences all participants while remaining unaffected by them. The four refinery

companies act as independent "players" responding to the dealer's actions. At each step, the environmental variables generate a market condition, and each company reacts to this condition by producing its corresponding stock price behaviour. Importantly, the relationships within the model are assumed to be unidirectional: global market variables influence domestic refinery stocks, while the domestic stocks themselves do not affect the global market indicators. Furthermore, based on the correlation analysis, no significant direct dependency was observed among the refinery companies themselves; therefore, each target variable was modelled independently.

To implement the predictive framework, three machine learning algorithms were initially evaluated: Random Forest Regression, Extreme Gradient Boosting (XGBoost), and Polynomial Regression. The dataset was divided into training and testing subsets using a standard train-test split in which 80% of the observations were allocated to training and 20% to testing. Model performance was evaluated using the coefficient of determination (R^2) and Root Mean Square Error (RMSE).

Experimental results demonstrated that the Random Forest algorithm achieved the highest predictive performance among the evaluated methods. The Random Forest model obtained an (R^2) value of approximately 0.989, outperforming both XGBoost and Polynomial Regression. Consequently, the remainder of the study was conducted using Random Forest models exclusively. For each refinery company, a separate Random Forest Regressor consisting of 50 decision trees was trained using the corresponding feature set.

A critical methodological aspect of this study concerns the prevention of look-ahead bias. In many financial forecasting studies, future information may unintentionally leak into the training process, producing unrealistically optimistic results. However, the structure of the present research substantially reduces this risk because the model is based on cross-market dependency rather than sequential autoregressive forecasting. The explanatory variables originate primarily from international markets operating in the New York trading session, while the target variables belong to the Tehran Stock Exchange. Since the New York trading session begins after the Tehran market has closed, information generated in global oil markets becomes available to Iranian investors only during the following trading day or later. Therefore, the direction of information flow is naturally aligned with real-world market timing.

For this reason, the use of a conventional shuffled train-test split does not introduce forward-looking contamination in the present framework. Unlike classical time-series forecasting models that rely heavily on sequential lag structures and temporal continuity, the proposed approach predicts stock prices based on the environmental conditions represented within each independent observation row. In other words, the model learns the relationship between market conditions and stock responses rather than attempting to extrapolate future values directly from previous prices. Consequently, the absence of rolling windows, lag generation, or walk-forward validation does not invalidate the methodology in this particular case. The temporal separation between the U.S. and Iranian trading sessions inherently prevents the model from accessing information that would not have been available at the prediction time in real market conditions.

To further validate the proposed framework, an additional out-of-sample evaluation was conducted approximately two months after the final observation included in the reference dataset. Real market values for Brent crude oil price, trading volume, and exchange rate variables were used as model inputs, and the predicted refinery stock prices were compared with actual market prices. The resulting prediction errors were 22% for Tabriz Oil Refining Company, 11% for Bandar Abbas Oil Refining Company, 9% for Isfahan Oil Refining Company, and 2% for Tehran Oil Refining Company. Although this secondary validation represents only a limited real-world case study, it provides additional evidence regarding the practical applicability of the proposed modelling framework.

Overall, the methodology proposed in this research combines cross-market dependency analysis with machine learning-based prediction while explicitly addressing common methodological issues observed in previous studies, including look-ahead bias and inappropriate application of deep learning models on limited financial datasets. The framework is specifically designed for the structural characteristics of the Tehran Stock Exchange and aims to provide a practically applicable predictive tool for investment decision-making in emerging oil-dependent markets.

4. *RESULTS AND ANALYSIS*

The dataset used in this study consists of 1,645 trading days with eight primary variables, including Brent crude oil price, Brent trading volume, USD/IRR exchange rate, and closing prices of four Iranian refinery companies (Tehran, Isfahan, Tabriz, and Bandar Abbas). After preprocessing and alignment, no missing values were observed, and all 1,645 samples were retained for modelling. The final feature set included Brent crude oil price, Brent trading volume, USD/IRR exchange rate, and three calendar-based temporal variables (day of year, month, and day of week), which were used to capture potential periodic effects in market behaviour.

Three regression models were evaluated for predicting refinery stock prices: Random Forest, XGBoost, and Polynomial Regression. The evaluation results indicate a clear performance gap between tree-based ensemble methods and polynomial regression. Random Forest achieved the highest predictive performance with an R^2 score of 0.9889 and an RMSE of 689.50. XGBoost followed closely with an R^2 of 0.9870 and an RMSE of 745.96, demonstrating comparable predictive capability with slightly higher error. In contrast, Polynomial Regression performed significantly worse, with an R^2 of 0.5127 and a substantially higher RMSE of 4569.83, indicating its inability to capture the nonlinear structure of the data.
Table 1 summarises the comparative performance of the evaluated models.

Table 1. Model Performance Comparison

Model	***R^2 Score***	***RMSE***
Random Forest	*0.9889*	*689.50*
XGBoost	*0.9870*	*745.96*
Polynomial Regression	*0.5127*	*4569.83*

The results clearly indicate that ensemble tree-based models are significantly more effective in capturing the nonlinear dependencies between global oil market variables and Iranian refinery stock prices. The marginal difference between Random Forest and XGBoost suggests that both models are robust, although Random Forest provides slightly better generalisation in this specific dataset.
In addition to numerical evaluation, a comparative visualization of model performance was generated. Figure 1 presents the R^2 and RMSE distribution across the three models, confirming the superiority of ensemble-based approaches in both accuracy and error minimisation.

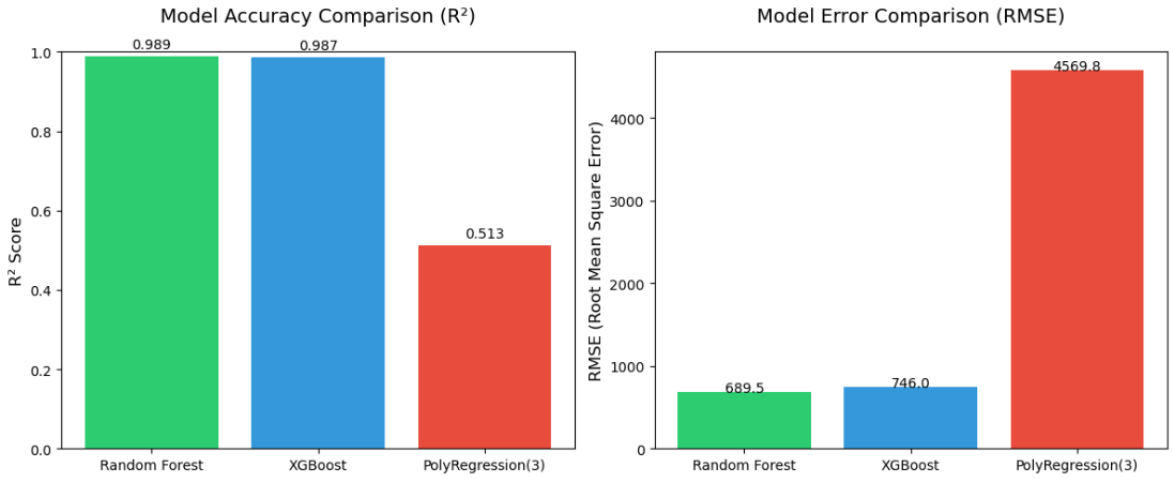

Figure 1. Comparison of R^2 and RMSE across models (Random Forest, XGBoost, Polynomial Regression)

Beyond offline evaluation, the proposed framework also supports an interactive prediction mechanism. In this setting, user-defined inputs such as Brent crude oil price, trading volume, USD/IRR exchange rate, and date-specific features are provided as a scenario vector. The trained models then generate real-time predictions for each refinery company independently. This structure allows the model to function not

only as a statistical evaluator but also as a practical decision-support tool, where hypothetical market conditions can be tested and their impact on Iranian refinery stock prices can be immediately observed.

Overall, the results demonstrate that global oil market variables contain strong predictive information for Iranian refinery stocks, and that nonlinear ensemble learning methods are particularly well-suited for modelling these relationships under the given data constraints.

5. *CONCLUSION*

This study proposed a machine learning framework for analysing cross-market dependencies between global oil market indicators and the stock prices of major Iranian refinery companies listed on the Tehran Stock Exchange (TSE). The results demonstrate that international oil-related variables, particularly Brent crude oil price, Brent trading volume, and the USD/IRR exchange rate, contain substantial predictive information regarding the behaviour of Iranian refinery stocks.

The empirical findings indicate that global energy market conditions can be effectively utilised to estimate the future prices of domestic refinery companies. The high predictive performance achieved by the Random Forest model (R^2 = 0.9889) confirms the existence of strong relationships between international oil market dynamics and the valuation of refinery firms operating within the Iranian market. These findings suggest that cross-market dependency analysis can provide practical value for financial decision-making, portfolio management, and risk assessment in emerging oil-dependent economies.

One of the important implications of this research is that investors and analysts may use global oil market indicators not only for macroeconomic interpretation but also as operational forecasting tools for domestic stock market analysis. In particular, changes in crude oil prices, trading volumes, and international energy market conditions may provide early signals regarding the future behaviour of refinery stocks. Consequently, the proposed framework may support portfolio allocation decisions, hedging strategies, and risk management processes in financial markets exposed to energy price fluctuations.

The comparative evaluation of machine learning algorithms also demonstrated that lightweight ensemble learning methods such as Random Forest and XGBoost outperform conventional polynomial regression approaches in modelling the nonlinear relationships between oil market variables and refinery stock prices. Among the evaluated methods, Random Forest achieved the best balance between prediction accuracy, robustness, computational efficiency, and interpretability. Unlike many deep learning architectures, the proposed framework does not require extremely large datasets, specialised hardware, or complex computational infrastructure. This characteristic is particularly important in the context of the Tehran Stock Exchange, where the amount of available historical data is relatively limited.

Another major contribution of this study is the development of a modelling framework that remains relatively simple, transparent, and understandable without requiring highly advanced financial expertise. The proposed approach can therefore serve as an accessible decision-support tool for researchers, analysts, and investors while still maintaining strong predictive capability. The lightweight nature of the model and its explainability constitute key strengths of the present research.

A further methodological contribution concerns the explicit consideration of temporal consistency between international and domestic financial markets. Due to the time difference between the New York trading session and the Tehran Stock Exchange, information generated in international oil markets becomes available before or during the following trading session in Tehran. Therefore, the proposed framework does not suffer from look-ahead bias despite the use of standard train-test splitting methods, because the prediction process inherently reflects a real-world forward information flow from global markets to domestic refinery stocks.

Although the proposed framework achieved strong predictive performance, several opportunities for future development remain available. The most promising extension involves integrating large language models (LLMs) and natural language processing techniques into the forecasting pipeline. International political and economic news, particularly news related to the U.S. dollar, monetary policy, sanctions, and geopolitical events, exerts substantial influence on global oil prices. Large language models could be employed to analyse financial news and estimate its potential impact on oil market conditions and currency strength. Such information could then be incorporated into the proposed prediction framework as additional explanatory signals, potentially improving forecasting accuracy.

Similarly, large language models could be applied to analyse domestic financial disclosures, including Codal announcements, corporate reports, and local economic news related to refinery companies. By combining structured numerical market data with unstructured textual information, future versions of the model may achieve a more comprehensive understanding of both global and domestic market dynamics.

In conclusion, this research demonstrates that relatively simple and computationally efficient machine learning models can successfully capture meaningful cross-market dependencies between international oil markets and Iranian refinery stocks. The findings highlight the practical usefulness of global market indicators for forecasting domestic stock prices and provide a foundation for future hybrid systems that combine machine learning, financial market analysis, and large language model-based news interpretation.

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