

Research Article

Predicting Stock Price Trend Using MACD Optimized by Historical Volatility

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With the rapid development of the financial market, many professional traders use technical indicators to analyze the stock market. As one of these technical indicators, moving average convergence divergence (MACD) is widely applied by many investors. MACD is a momentum indicator derived from the exponential moving average (EMA) or exponentially weighted moving average (EWMA), which reacts more significantly to recent price changes than the simple moving average (SMA). Traders find the analysis of 12- and 26-day EMA very useful and insightful for determining buy-and-sell points. The purpose of this study is to develop an effective method for predicting the stock price trend. Typically, the traditional EMA is calculated using a fixed weight; however, in this study, we use a changing weight based on the historical volatility. We denote the historical volatility index as HVIX and the new MACD as MACD-HVIX. We test the stability of MACD-HVIX and compare it with that of MACD. Furthermore, the validity of the MACD-HVIX index is tested by using the trend recognition accuracy. We compare the accuracy between a MACD histogram and a MACD-HVIX histogram and find that the accuracy of using MACD-HVIX histogram is 55.55% higher than that of the MACD histogram when we use the buy-and-sell strategy. When we use the buy-and-hold strategy for 5 and 10 days, the prediction accuracy of MACD-HVIX is 33.33% and 12% higher than that of the traditional MACD strategy, respectively. We found that the new indicator is more stable. Therefore, the improved stock price forecasting model can predict the trend of stock prices and help investors augment their return in the stock market.

1. Introduction

Securities investment is a financial activity influenced by many factors such as politics, economy, and psychology of investors. Its process of change is nonlinear and multifractal [1]. The stock market has high-risk characteristics; i.e., if the stock price volatility is excessive or the stability is low, the risk is uncontrollable. Financial asset returns in the short term are persistent; however, those in the long term will be reversed [2].

Asness [3] reported that the stock, foreign exchange, and commodity markets have a trend. Hassan [4] noted that complex calculations are not particularly effective for predicting stock markets. Many trend analysis indicators and prediction methods for financial markets have been proposed. Pai [5] used Internet search trends and historical trading data to predict stock markets using the least squares support vector regression model. Lahmiri [6] accurately

predicted the minute-ahead stock price by using singular spectrum analysis and support vector regression. Researchers have also used other methods to forecast stock markets. Singh et al. [7] designed a forecasting model consisting of fuzzy theory and particle swarm optimization to predict stock markets using historical data from the State Bank of India. Lahmiri et al. [8] proposed an intelligent ensemble forecasting system for stock market fluctuations based on symmetric and asymmetric wavelet functions. Das et al. [9] proposed a hybridized machine-learning framework using a self-adaptive multipopulation-based Jaya algorithm for forecasting the currency exchange value. Laboissiere et al. [10] developed a model involving correlation analysis and artificial neural networks (NNs) to predict the stock prices of Brazilian electric companies. Lei [11] proposed a wavelet NN prediction method for the stock price trend based on rough set attribute reduction. Lahmiri [12] used variational mode decomposition to forecast the intraday stock price.

Lahmiri [13] addressed the problem of technical analysis information fusion and reported that technical information fusion in an NN ensemble architecture improves the prediction accuracy. In [14], the authors argued that time series of stock prices are nonstationary and highly noisy. This led the authors to propose the use of a wavelet denoising-based backpropagation (WDBP) NN for predicting the monthly closing price of the Shanghai composite index. Shynkevich et al. [15] investigated the impact of varying the input window length and the highest prediction performance was observed when the input window length was approximately equal to the forecast horizon. In [16], a prediction model based on the input/output data plan was developed by means of the adaptive neurofuzzy inference system method representing the fuzzy inference system. Zhou et al. [17] proposed a stock market prediction model based on high-frequency data using generative adversarial nets. Wang et al. [18] used a bimodal algorithm with a data-divider to predict the stock index. In [19], the author used multiresolution analysis techniques to predict the interest rate next-day variation. Using K-line patterns' predictive power analysis, Tao et al. [20] found that their proposed approach can effectively improve prediction accuracy for stock price direction and reduce forecast error.

We will introduce the concept of moving average convergence divergence (MACD) and help the readers understand its principle and application in Section 2. Although the MACD oscillator is one of the most popular technical indicators, it is a lagging indicator. In Section 3, we propose an improved model called MACD-HVIX to deal with the lag factor. In Section 4, data for empirical research are described. Finally, in Section 5, we develop a trading strategy using MACD-HVIX and employ actual market data to verify its validity and reliability. We also compare the prediction accuracy and cumulative return of the MACD-HVIX histogram with those of the MACD histogram. The performance of MACD-HVIX exceeds that of MACD. Therefore, the trading strategy based on the MACD-HVIX index is useful for trading. Section 6 presents our conclusion.

2. MACD and Its Strategy

MACD evolved from the exponential moving average (EMA), which was proposed by Gerald Appel in the 1970s. It is a common indicator in stock analysis. The standard MACD is the 12-day EMA subtracted by the 26-day EMA, which is also called the DIF. The MACD histogram, which was developed by T. Aspray in 1986, measures the signed distance between the MACD and its signal line calculated using the 9-day EMA of the MACD, which is called the DEA. Similar to the MACD, the MACD histogram is an oscillator that fluctuates above and below the zero line. The construction formula is as follows:

$$EMA_t^m(S_t) = (1 - \alpha) EMA_{t-1}^m + \alpha \times S_t \quad (t > 1),$$

$$EMA_1^m = S_1,$$

$$MACD_t = DIF_t = EMA_t^m(S_t) - EMA_t^n(S_t),$$

$$DEA_t = EMA_t^p(DIF_t),$$

$$OSC_t = DIF_t - DEA_t, \quad (1)$$

where $m = 12$, $n = 26$, and $p = 9$. The weight number α is a fixed value equal to $2/(m + 1)$. The number of the MACD histogram is usually called the MACD bar or OSC. The analysis process of the cross and deviation strategy of DIF and DEA includes the following three steps.

(i) Calculate the values of DIF and DEA.

(ii) When DIF and DEA are positive, the MACD line cuts the signal line in the uptrend, and the divergence is positive, there is a buy signal confirmation.

(iii) When DIF and DEA are negative, the signal line cuts the MACD line in the downtrend, and the divergence is negative, there is a sell signal confirmation.

3. MACD-HVIX Weighted by Historical Volatility and Its Strategy

The essence of a good technical indicator is a smooth trading strategy; i.e., the constructed index must be a stationary process. We present an empirical study in Section 5. The validity and sensitivity of MACD have a strong relationship with the choice of parameters. Different investors choose different parameters to achieve the best return for different stocks. In this study, the weight is based on the historical volatility. It is expected that the accuracy and stability of MACD can be improved. The construction formula is as follows:

$$\begin{aligned} & (EMA - HVIX)_t^m(S_t) \\ &= \frac{\sum_{i=1}^m \sigma_{t-i}}{\sum_{i=0}^m \sigma_{t-i}} (EMA - HVIX)_{t-1}^m + \frac{\sigma_t}{\sum_{i=0}^m \sigma_{t-i}} S_t \\ & \quad (t > 1), \end{aligned} \quad (2)$$

$$(EMA - HVIX)_1^m = S_1,$$

$$(MACD - HVIX)_t = (DIF - HVIX)_t$$

$$= (EMA - HVIX)_t^m(S_t) - (EMA - HVIX)_t^n(S_t),$$

$$(DEA - HVIX)_t = EMA_t^p((DIF - HVIX)_t),$$

$$(OSC - HVIX)_t = (DIF - HVIX)_t - (DEA - HVIX)_t.$$

Here, the weight changes over time; HVIX is the change index of the historical volatility of a stock. The HVIX in this paper is the change index of the volatility in the past days. It is similar to the market volatility index VIX used by the Chicago options exchange. It reflects the panic of the market to a certain extent; thus, it is also called the panic index. The above process is expressed by the code shown in Algorithm 1.

The analysis process of the cross and deviation strategy of DIF-HVIX and DEA-HVIX includes the following three steps.

(i) Calculate the values of DIF-HVIX and DEA-HVIX.

(ii) When DIF-HVIX and DEA-HVIX are positive, the MACD-HVIX line cuts the signal line of HVIX in the

Require: Set up parameters

The stock closing price is S_{close} , the historical volatility index is $HVIX$, the length of the closing stock price data is N_L , the weight of EMA is $Alpha$, the weight of EMA_HVIX is $Alpha_HVIX$, and the time parameters are m and n .

for $j=1$ to $(N_L - m + 1)$ **do**

sum=0;

for $i=j$ to $(j+m - 2)$ **do**

⇒Generate return series

$$R_i = \log \left(\frac{S_{closei+1}}{S_{closei}} \right)$$

⇒Sum the return in the past $m - 1$ days

sum=sum+ R_i

Calculate the mean return in the past $m - 1$ days

$$R_mean = \frac{\text{sum}}{(m - 1)}$$

sum=0

for $i=j$ to $(j+m - 2)$ **do**

$$Var_i = (R_i - R_mean)^2$$

⇒Sum the variance in the past $m - 1$ days

sum=sum+ Var_i ;

Calculate the standard deviation in the past $m - 1$ days

$$Std_j = \sqrt{\frac{\text{sum}}{m - 2}}$$

for $j=1$ to $(N_L - 2m + 2)$ **do**

sum1=0

for $i=j$ to $(j+m - 1)$ **do**

sum1=sum1+ Std_i ;

sum2=0;

for $i=j$ to $(j+m - 2)$ **do**

sum2=sum2+ Std_i ;

Calculate $Alpha_HVIX$

$$Alpha_HVIX_j = 1 - \frac{\text{sum2}}{\text{sum1}}$$

for $i=2$ to $(N_L - 2m + 2)$ **do**

$$EMA_HVIX_i = (1 - Alpha_HVIX_{i-1}) \times EMA_HVIX_{i-1} + Alpha_HVIX_{i-1} \times S_{closei+2m-2}$$

Calculate $Diff_HVIX$ and DEA_HVIX

$$Diff_HVIX = EMA_HVIX^m - EMA_HVIX^n$$

Calculate DEA_HVIX

$$DEA_HVIX(1) = \frac{\sum_{i=1}^p DIF_HVIX}{p}$$

$$Alpha^m = \frac{2}{m + 1}$$

for $i=2$ to $\text{length}(Diff_HVIX) - p + 1$ **do**

$$DEA_HVIX_i = (1 - Alpha^m) \times DEA_HVIX_{i-1} + Alpha^m \times Diff_HVIX_{i+p-1}$$

Calculate OSC_HVIX

$$OSC_HVIX = Diff_HVIX - DEA_HVIX$$

ALGORITHM 1: General algorithm for HVIX and EMA-HVIX.

uptrend, and the divergence is positive, there is a buy signal confirmation.

- (iii) When DIF_HVIX and DEA_HVIX are negative, the signal line of $HVIX$ cuts the $MACD_HVIX$ line in the downtrend, and the divergence is negative, there is a sell signal confirmation.

4. Data Description

We first perform an empirical study on the buy-and-sell strategy, which involves buying today and selling tomorrow.

We use the historical data for the stock “-zgrs-” from November 2, 2015, to September 21, 2017, from the Shanghai stock market. First, we develop the strategy for the new index and calculate the prediction accuracy and cumulative return of the stock with two different indicators. Then, we compare the accuracy rate and cumulative return. The accuracy here is calculated according to whether the stock price rises on the second day. Furthermore, we test a buy-and-hold strategy for the proposed model. The buy-and-hold strategy is a trading strategy in which the traders hold the stock for a while instead of selling it on the next trading day. We use the historical data for the stock “-dggf-” from July 27, 2009, to November

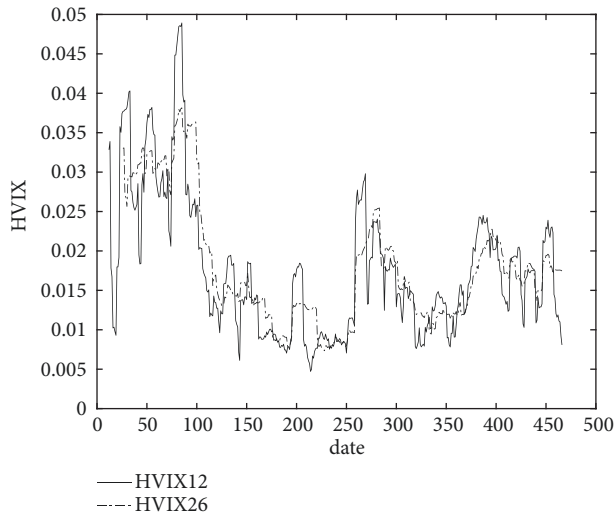


FIGURE 1: Historical volatility of “-zgrs-” with the buy-and-sell strategy.

3, 2017, from the Shanghai stock market to test a 5 d buy-and-hold strategy and use the historical data for the stock “-payh-” from June 22, 1993, to May 10, 2010, from the Shanghai stock market to test a 10 d buy-and-hold strategy. The detailed trading strategy is similar to the buy-and-sell strategy. Here, we use $m = 12$, $n = 26$, and $p = 9$.

5. Empirical Results

5.1. Empirical Results of Buy-and-Sell Strategy. From the “-zgrs-” stock data chosen in Section 4, we calculate the HVIX of the past m days and the past n days. A higher stock index means that investors feel anxiety regarding the stock market, and a lower stock index means that the rate of change of the stock price will decrease. Figure 1 shows the HVIX index.

Next, using the calculated volatility index, we calculate the weight of the EMA formula in Section 3 and obtain the values of MACD-HVIX, DEA-HVIX, and OSC.

Figure 2 shows the candlestick chart and MACD histogram. In the candlestick chart, the blue line represents the 12-d EMA, and the red line represents the 26-d EMA. Candlesticks are usually composed of a red and green body, as well as an upper wick and a lower wick. The area between the opening and the closing prices is called the *body*, and price excursions above or below the real body are called the *wick*. The body indicates the opening and closing prices, and the wick indicates the highest and lowest traded prices of a stock during the time interval represented. For a red body, the opening price is at the bottom, and the closing price is at the top. For a green body, the opening price is at the top, and the closing price is at the bottom.

In the MACD histogram, the solid line represents the DIF, the dotted line represents the DEA, and the histogram represents the MACD bar. According to the strategy described in Section 3, we buy the stock when the DIF and DEA are positive, the DIF cuts the DEA in an uptrend, and the

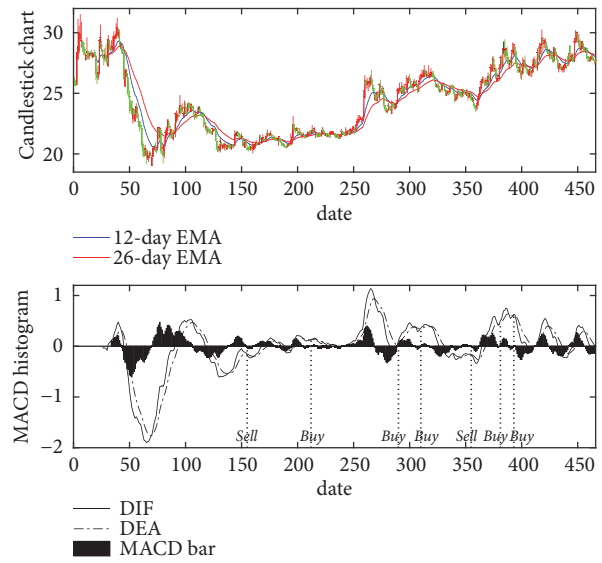


FIGURE 2: Candlestick chart and MACD histogram for “-zgrs-” with the buy-and-sell strategy. (For interpretation of the references to color in the figure, the reader is referred to the web version of the article.)

divergence is positive. We sell the stock when the DEA cuts the DIF in a downtrend, and the divergence is negative. As shown in Figure 2, we sell the stock on days 155 and 355 and buy the stock on days 212, 290, 310, 381, and 393. The buy-and-sell signals in the candlestick chart and the MACD histogram are shown in Figure 3.

Figure 4 shows the candlestick chart and MACD histogram of HVIX. In the candlestick chart, the blue line represents the 12-d EMA-HVIX, and the red line represents the 26-d EMA-HVIX. In the MACD-HVIX histogram, the solid line represents the DIF-HVIX, the dotted line represents the DEA-HVIX, and the histogram represents the MACD-HVIX bar. According to the strategy described in Section 3, we buy the stock when the DIF-HVIX and DEA-HVIX are positive, the DIF-HVIX cuts the DEA-HVIX in an uptrend, and the divergence is positive, and we sell the stock when the DEA-HVIX cuts the DIF-HVIX in a downtrend, and the divergence is negative. As shown in Figure 4, we sell the stock on days 118 and 187 and buy the stock on days 222, 231, 241, 243, 292, 415, and 447. The buy-and-sell signals in the candlestick chart and the MACD histogram are shown in Figure 5.

To verify the stability of the new indicator, we compare the MACD and MACD-HVIX in Figure 6. The MACD and MACD-HVIX have basically the same trend and the stability of the MACD-HVIX is better than that of the MACD.

Table 1 shows a comparison of the specific values of the buying-selling points for the MACD index and MACD-HVIX index, as well as a comparison of the predicted and actual trends. Here, we see that the prediction accuracy of MACD-HVIX is 0.667 and that of MACD is 0.4286. By using the proposed indicator, we can improve the prediction accuracy by 55.55% compared with the traditional MACD. The “-Price-” in the table represents the closing price of

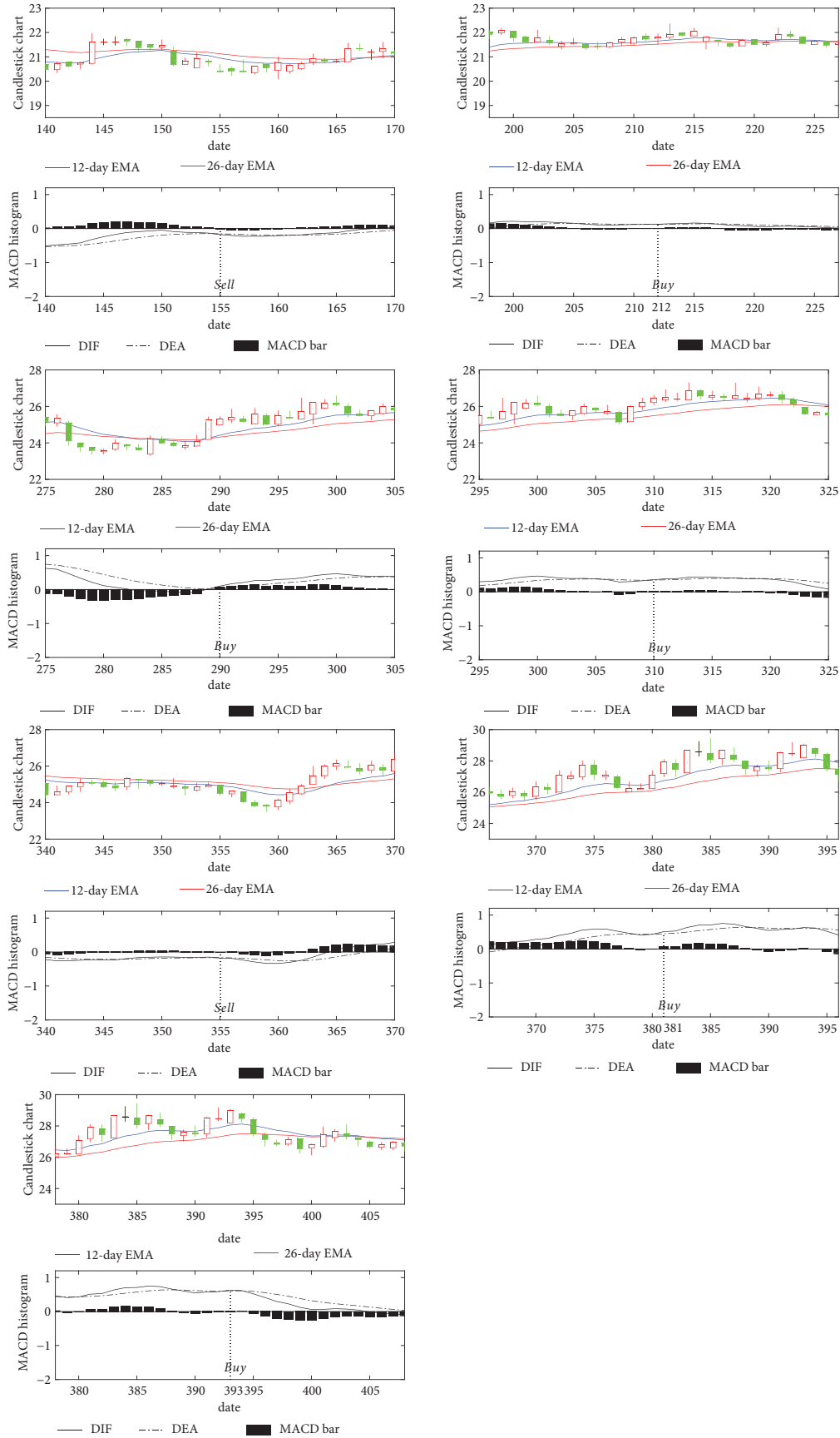


FIGURE 3: Buy-and-sell signals in the candlestick chart and MACD histogram for the buy-and-sell strategy.

TABLE 1: Comparison of the specific values of the buying-selling points for the buy-and-sell strategy.

	Test date	Price_(Test date)	Price_(Test date+_1 d)	Predicted trend	Actual trend
MACD	155	20.39	20.42	↓	↑
	212	21.82	21.93	↑	↑
	290	25.32	25.38	↑	↑
	310	26.44	26.50	↑	↑
	355	24.51	24.62	↓	↑
	381	27.93	27.45	↑	↓
	393	29.00	28.48	↑	↓
Win rate	0.4286				
MACD-HVIX	118	22.24	21.90	↓	↓
	187	20.80	20.66	↓	↓
	222	21.90	21.84	↑	↓
	231	21.80	21.67	↑	↓
	241	21.65	21.58	↑	↓
	243	21.78	21.83	↑	↑
	292	25.18	25.58	↑	↑
	415	27.98	28.80	↑	↑
447	29.27	29.51	↑	↑	
Win rate	0.6667				

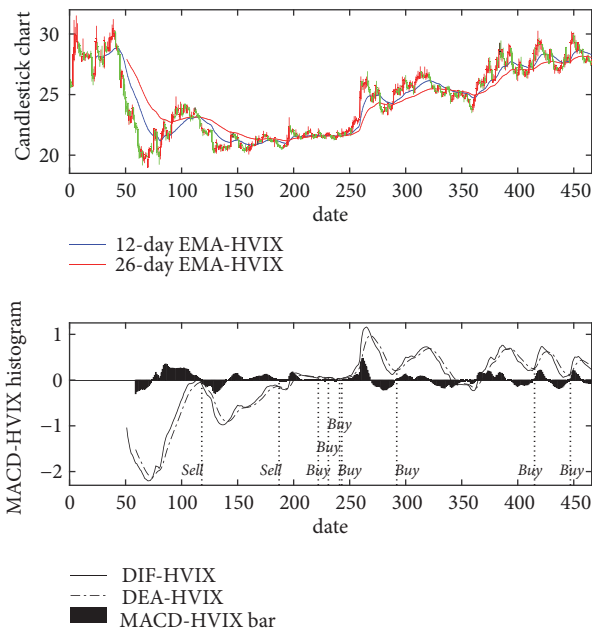


FIGURE 4: Candlestick chart and MACD-HVIX histogram for “-zgrs-” with the buy-and-sell strategy. (For interpretation of the references to color in this figure, the reader is referred to the web version of the article.)

stock. Next, we compare the cumulative returns for the two indicators. According to the trading points shown in the table, we perform a simulation test. We assume that the initial fund is 1 million. The cumulative returns under the two indexes are 1.1136 million and 1.3365 million, for MACD and MACD-HVIX indices, respectively.

5.2. Empirical Results of Buy-and-Hold Strategy. Using the “-dggf-” stock data chosen in Section 4, we first investigate the buy or sell points for both the indicators with the buy-and-hold strategy applied for 5 d. Then, we compare the prediction accuracy between the two indicators. The MACD histogram shown in Figure 7 indicates the buy-and-sell points; we should buy the stock at a buy point on days 391, 1,071, 1,181, 1,326, and 1,481, and sell the stock at a sell point on days 791, 881, and 911. The prediction situation is shown in Table 2.

The MACD-HVIX histogram in Figure 8 indicates the buy-and-sell points. We should buy the stock at a buy point on days 371, 1,201, 1,331, and 1,561 and sell the stock at a sell point on days 751 and 771. The prediction situation is shown in Table 2. A comparison between MACD and MACD-HVIX is shown in Figure 9.

Table 2 shows a comparison of the specific values of the buying-selling points for the MACD and MACD-HVIX indices with the buy-and-hold strategy for 5 d, as well as a comparison of the predicted and actual trends. Here, we observe that the prediction accuracy of MACD-HVIX is 0.8333 and that of MACD is 0.6250. By using the proposed indicator, we can improve the prediction accuracy by 33.33% compared with the traditional MACD. The “-Price-” in the table represents the closing price of the stock.

Next, using the “-payh-” stock data chosen in Section 4, we investigate the buy or sell points for both the indicators with the buy-and-hold strategy applied for 10d. Then, we compare the prediction accuracy between the two indicators. The MACD histogram in Figure 10 indicates the buy-and-sell points. We should buy the stock at a buy point on day 901, and sell the stock at a sell point on days 621, 1,971, 2,071, 2,291, 2,431, and 2,661. The prediction situation is shown in Table 3.

The MACD-HVIX histogram in Figure 11 indicates the buy-and-sell points. We should buy the stock at a buy point

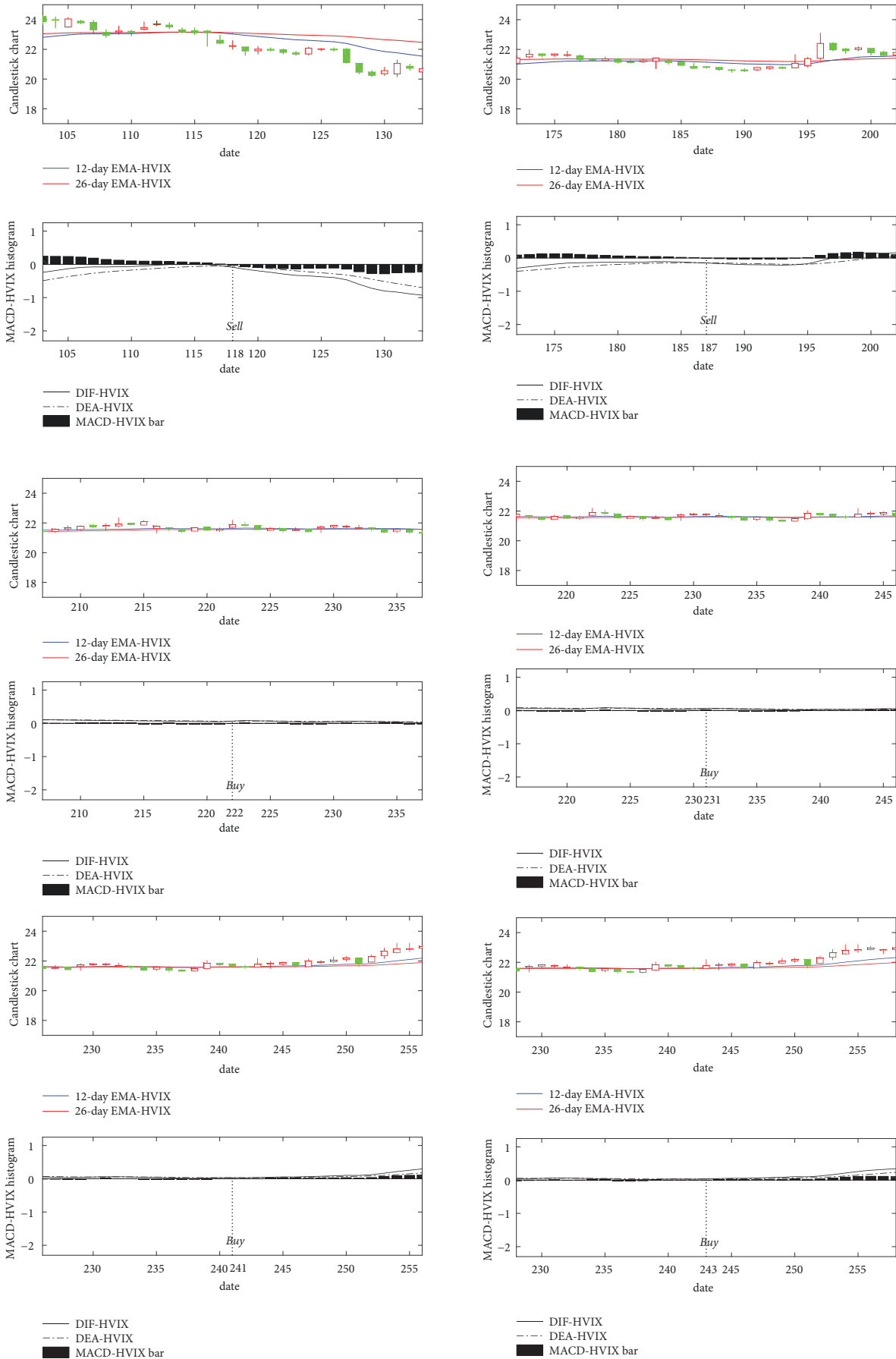


FIGURE 5: Continued.

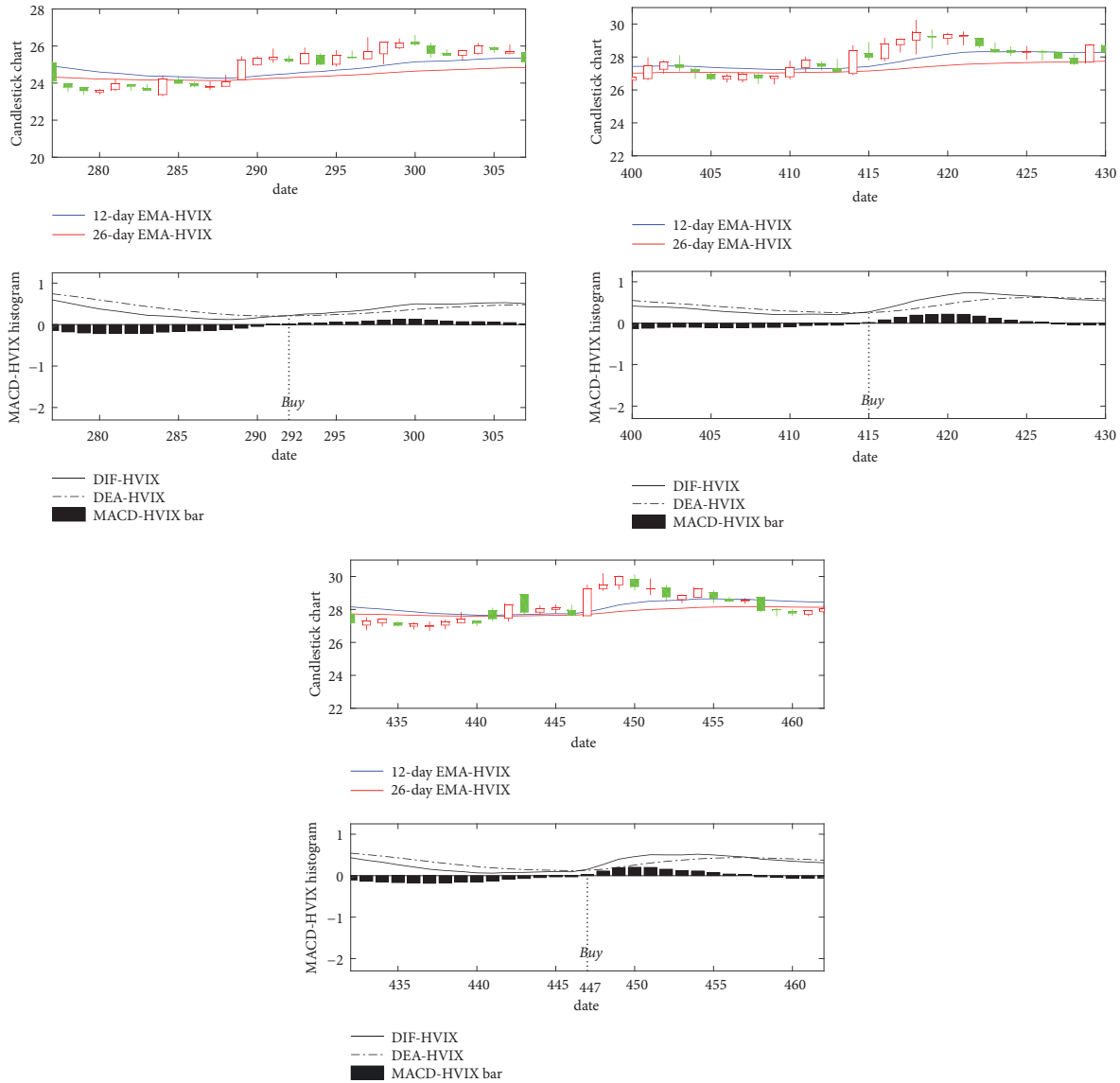


FIGURE 5: Buy-and-sell signals in the candlestick chart and the MACD-HVIX histogram for the buy-and-sell strategy.

on day 901 and sell the stock at a sell point on days 2,071, 2,421, 2,661, and 2,741. The prediction situation is shown in Table 3. A comparison of MACD and MACD-HVIX is presented in Figure 12.

Table 3 shows the comparison of the specific values of the buying-selling points for the MACD and MACD-HVIX indices with the buy-and-hold strategy applied for 5 d, as well as a comparison of the predicted and actual trends. Here, we observe that the prediction accuracy of MACD-HVIX is 0.8 and that of MACD is 0.7143. By using the proposed indicator, we can improve the prediction accuracy by 12% compared with the traditional MACD. The “-Price-” in the table represents the closing price of the stock.

5.3. Computational Complexity. The computational complexity of the MACD and MACD-HVIX for a stock which

has a length of n are $O(N)$ and $O(N^2)$, respectively. In terms of trend prediction processing time, the average time required to process a buy-and-sell strategy, a buy-and-hold strategy for 5 days, and a buy-and-hold strategy for 10 days with the MACD approach (MACD-HVIX) are, respectively, 1.25 (1.51), 1.12 (1.35), and 1.41 seconds (1.58) using Matlab R2017b on an Intel(R) Core(TM) i5-6200 CPU @ 2.30GHz processor.

6. Conclusion

As indicated by Tables 1, 2, and 3, we buy-and-sell stock based on improved MACD; then we found all the accuracy is higher than that before the improvement. Therefore, the improved model has higher maneuverability in securities investment and allows investors to capture every buy-and-sell points in

TABLE 2: Comparison of the specific values of the buying-selling points with the buy-and-hold strategy applied for 5 d.

	Test date	Price_(Test date)	Price_(Test date+_5 d)	Predicted trend	Actual trend
MACD	391	13.04	15.70	↑	↑
	791	4.81	5.19	↓	↑
	881	5.55	5.61	↓	↑
	911	5.71	5.59	↓	↓
	1071	6.57	6.74	↑	↑
	1181	6.66	6.95	↑	↑
	1326	10.70	11.93	↑	↑
	1481	17.28	13.51	↑	↓
Win rate			0.6250		
MACD-HVIX	371	11.68	12.00	↑	↑
	751	5.53	5.75	↓	↑
	771	5.76	5.62	↓	↓
	1201	7.66	7.83	↑	↑
	1331	11.93	12.23	↑	↑
	1561	16.89	19.05	↑	↑
Win rate			0.8333		

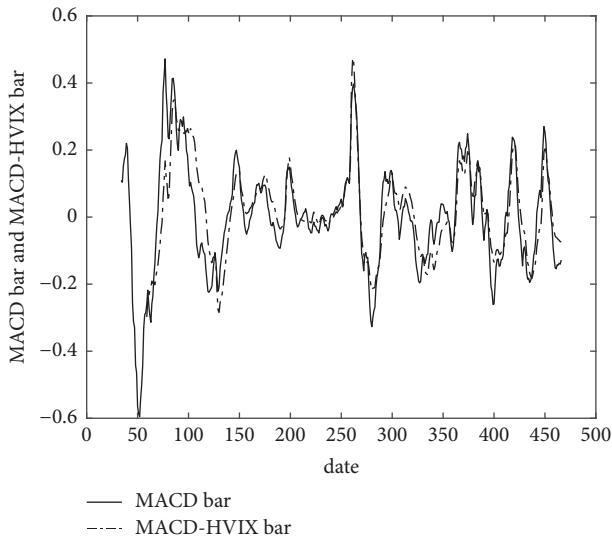


FIGURE 6: Comparison of the two indicators for the buy-and-sell strategy.

the market. For both the buy-and-sell strategy and the buy-and-hold strategy, the empirical results indicated that the proposed model can make more precise predictions than the traditional model. The proposed model was tested with three different stocks and it generated the high prediction accuracy for all the cases. In addition, while a smoothing index is used to construct the MACD index and the impact of the past price declines exponentially, the MACD-HVIX does not have this property. Although the MACD-HVIX index is improved compared with the MACD index, the stationarity of the MACD-HVIX index is difficult to prove theoretically. Test shows that it is stable; however, in the ever-changing market, an abnormal situation can cause incalculable losses to

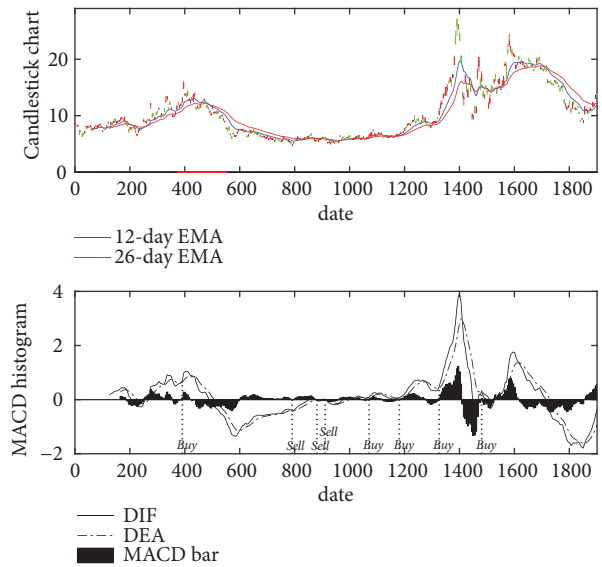


FIGURE 7: Candlestick chart and MACD histogram for “-dggf-” with the buy-and-hold strategy applied for 5 d. (For interpretation of the references to color in this figure, the reader is referred to the web version of the article.)

investors. In future research, we will investigate other factors for the model by constantly updating the data and the training model to obtain a better prediction effect.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

TABLE 3: Comparison of the specific values of the buying-selling points with the buy-and-hold strategy applied for 10 d.

	Test date	Price_(Test date)	Price_(Test date+_10 d)	Predicted trend	Actual trend
MACD	621	6.59	6.23	↓	↓
	901	18.87	19.05	↑	↑
	1971	13.05	13.22	↓	↑
	2071	12.25	10.31	↓	↓
	2291	11.11	10.52	↓	↓
	2431	10.56	10.81	↓	↑
	2661	8.51	8.23	↓	↓
Win rate			0.7143		
MACD-HVIX	901	18.87	19.05	↑	↑
	2071	12.25	10.31	↓	↓
	2421	11.30	10.56	↓	↓
	2661	8.51	8.23	↓	↓
	2741	6.95	7.19	↓	↑
Win rate			0.8000		

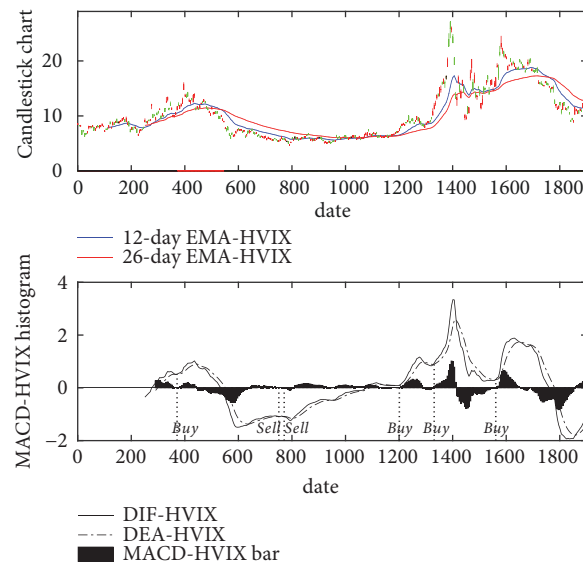


FIGURE 8: Candlestick chart and MACD-HVIX histogram for “-dggf-” with the buy-and-hold strategy for 5 d. (For interpretation of the references to color in this figure, the reader is referred to the web version of the article.)

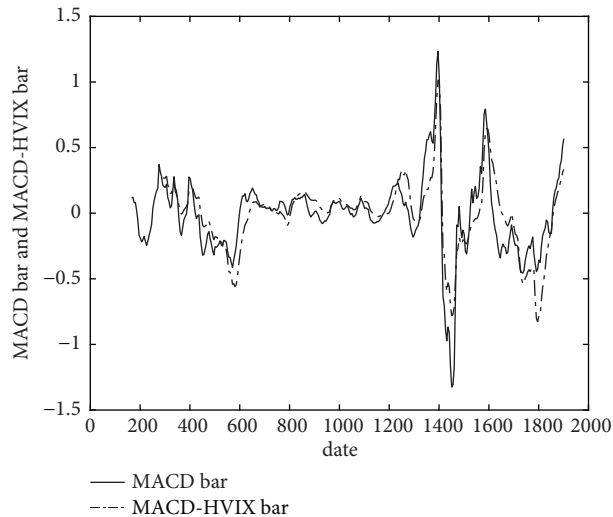


FIGURE 9: Comparison of the two indicators with the buy-and-hold strategy applied for 5 d.

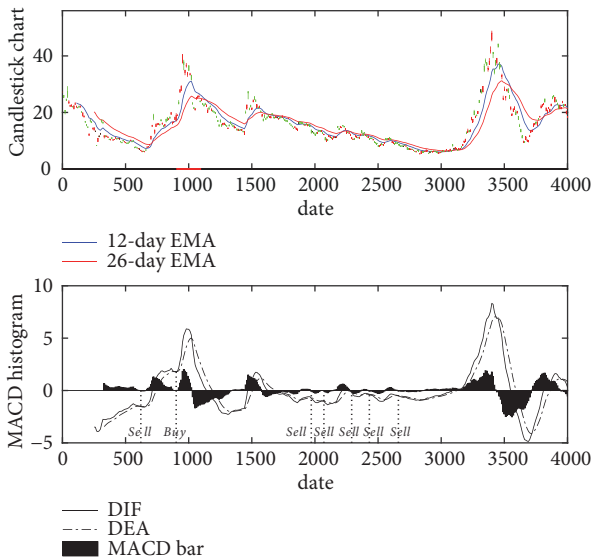


FIGURE 10: Candlestick chart and MACD histogram for “-payh-” with the buy-and-hold strategy applied for 10 d. (For interpretation of the references to color in this figure, the reader is referred to the web version of the article.)

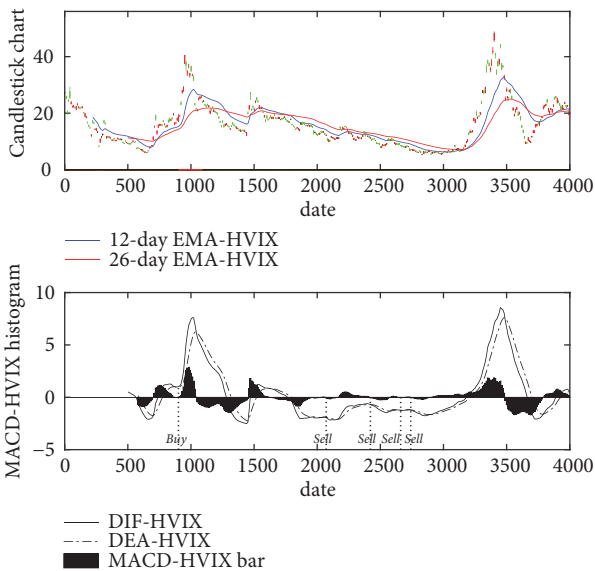


FIGURE 11: Candlestick chart and MACD-HVIX histogram for “-payh-” with the buy-and-hold strategy applied for 10 d. (For interpretation of the references to color in this figure, the reader is referred to the web version of the article.)

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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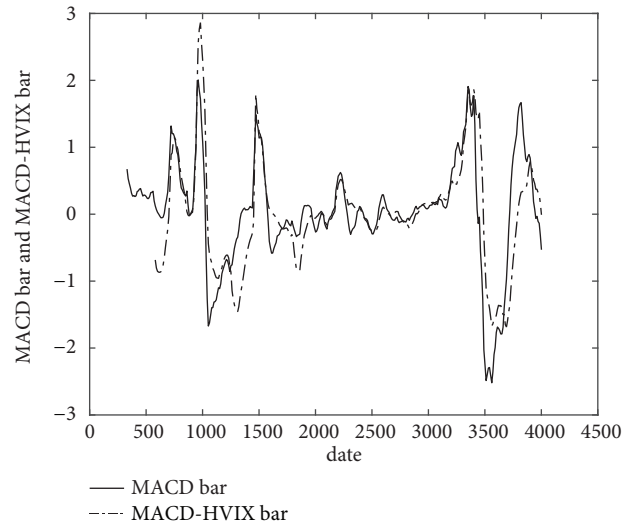


FIGURE 12: Comparison of the two indicators with the buy-and-hold strategy applied for 10 d.

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