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An Empirical Study on the Efficiency of the Chinese Stock Market

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Abstract

This article conducts research on the daily closing prices and yields of the Shanghai Composite Index and the Shenzhen Composite Index from January 2, 2014 to January 2, 2020. Based on the random walk assumption, the unit root test, the run test and the autocorrelation test were used to examine the efficiency of Shanghai Stock Exchange and Shenzhen Stock Exchange respectively. According to the findings, both Shanghai and Shenzhen stock markets have reached weak-form market efficiency. Because the three tests cannot prove whether there is a relationship between the Shanghai and Shenzhen stock markets, this article uses the Johansen cointegration test and the Granger causal test to determine whether the Shanghai and Shenzhen stock markets are joint weak-form market efficiency. The results reveal that there is no cointegration relation between the closing prices of Shanghai and Shenzhen Composite Index, but the daily yield of Shanghai and Shenzhen Composite Index can predict each other to some extent. Therefore, it is deduced that Shanghai and Shenzhen stock markets has not attained the joint weak-form market efficiency.

Keywords: *Efficient Markets Hypothesis; Unit Root Test; Run Test; Johansen Cointegration Test; Granger Causality Test.*

1. INTRODUCTION

The efficiency of the capital market has been a topic about the financial field for a long time. Many researchers tried to test the efficiency of the market in the view of the efficient market hypothesis. As one of the foundations of the current system of financial theory, this hypothesis was widely applied to test the efficiency of different markets.

In the 20th century, many economists began to explore the efficiency of the capital market. In 1965, an essay which was posted on a financial magazine by Fama marked the formation of the efficient market hypothesis [5]. And in 1970, the Efficient Markets Hypothesis was put forward by Fama [4]. This theory acknowledged that in a stock market which is of sound laws, stable functions, high grade of transparency and full competition, all invaluable information is accurately and fully reflected in the trend of the price of the stock. The efficient market was divided into three categories by different information collection: weak-form efficient market, semi-strong form market and strong form market. In the weak-form market efficiency, the prices of stock fully reflect the historical information in the transaction. Therefore, it's impossible for any investors to gain excess profits by analyzing past prices without manipulation. This paper mainly discusses the weak-form efficiency of Chinese stock market.

There is lots of literature on testing the efficiency of the markets. This paper introduces them from two perspectives: research methods and research objects. In terms of the research methods, the common research methods are mainly run test, unit root test and so forth. Lo explored the efficiency of American stock market and put forward the idea of variance ratio test for the first time [1]. Zhang used the unit root test and event study method to research the weak-form market efficiency of Chinese stock market and they got the conclusion that the weak-form market efficiency of Chinese stock market has not attained the level of semi-strong efficiency [12]. Jefferis and Smith employed a generalized autoregressive

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conditional heteroskedasticity approach with time-varying parameters related weak-form market efficiency to stock market turnover, capitalization and institutional characteristics of markets of some African countries [7]. Zhang, Chen and Tian employed non-parametric statistics which were used to test martingale difference series to test weak-form market efficiency of Chinese stock market and they drew the conclusion that the degree of weak-form market efficiency of Chinese stock market has been improved in recent years [8]. Fawson et al. employed the Ljung-Box Q-test, binomial distribution test, run test and the unit root test, and finally suggested that the Taiwan stock market was of weak-form market efficiency according to the monthly stock price [2].

As for research objects, researchers tested the efficiency of capital markets of different countries, such as Russia, Romania and Thailand. Darushin et al. applied a nonparametric statistical method to test the weak-form market efficiency of Russian stock market and it remained weak-form efficient despite unfavorable conditions [6]. Moldovan analyzed the daily evolution of the Romanian BET-FI index for 8 years and they found that Romanian stock market was not weak-form efficient [3]. Jenwittayaroje employed three weak-form market efficiency tests: autocorrelation tests, run tests, and variance ratio tests and he found Thailand stock exchange became more weak-form market efficient over time [9]. Different countries were of different levels of efficiency due to the difference of economic levels and other factors.

To sum up, the efficiency of the markets is a significant concept and there are many studies about it. On account of the different research methods and data sources, these former studies didn't reach a consensus. This essay tests the weak-form market efficiency of the Chinese stock markets through the data analysis of Shanghai Composite index (SSEC) and Shenzhen Component index (SZI) from January 2, 2014 to January 2, 2020, which is a total of 1465 daily closing prices. Unit root test, run test and autocorrelation test are employed in this essay.

2. METHODOLOGY

2.1. Data selection and processing

As to overcome the defects of the insufficient number of sample and short time interval, the article uses the daily closing prices of SSEC and SZI from January 2, 2014 to January 2, 2020. On the representativeness of Chinese stock market trend, SSEC is compiled by Shanghai Stock Exchange, calculated with the total volume of the stocks issued on the stock exchange as the weights, and reflects the general movement of Shanghai Stock Exchange. Meanwhile, SZI is compiled by Shenzhen Stock Exchange and takes all the stocks issued on Shenzhen Stock Exchange as the calculation scope and the issued volumes as the weights, which can comprehensively reflect the movement of the stock prices on Shenzhen Stock Exchange.

Because there are market closures and stoppages in the two exchanges during the sample time interval, these market closures are automatically excluded in the analysis and this article selects the time when there are transactions to be analyzed. There are 1465 daily closing price data available for the SSEC and 1465 daily closing price data available for the SZI.

The yield of stock markets is calculated by logarithmic method:

$$r_t = 100 \times ln \frac{y_t}{y_{t-1}} \tag{1}$$

In the above formula, r_t is the yield of stock market at day t, y_t is the price of stock market at day t.

Some of the raw data are listed in TABLE 1.

TABLE 1. DAILY CLOSING PRICE AND YIELD OF SSEC AND SZI

Date	SSEC		SZI	
	Closing price	*Yield*	*Closing price*	*Yield*
2014-01-02	2109.387	-0.31197	8114.388	-0.09115
2014-01-03	2083.136	-1.25229	8028.33	-1.06622
...	...	...	...	...
2017-01-03	3135.921	1.03481	10262.85	0.838642
2017-01-04	3158.794	0.726746	10384.87	1.181942
2017-01-05	3165.411	0.209256	10371.47	-0.12908
...	...	...	...	...
2019-12-31	3050.124	0.331687	10430.77	0.623264
2020-01-02	3085.198	1.143346	10638.83	1.975029

The data comes from NetEase Finance and Economics which is authentic in Chinese stock markets. The time series chart of closing prices is shown in Fig. 1.

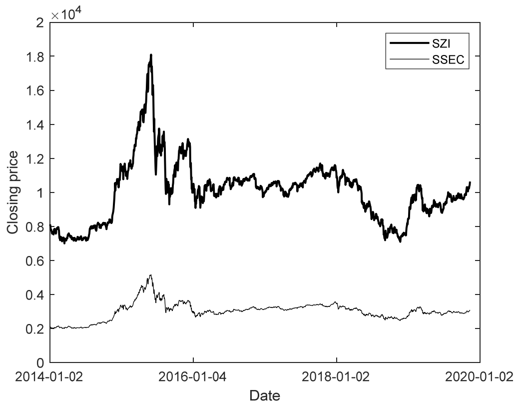


Figure 1. Closing Prices of SSEC and SZI

2.2. Unit root test

To examine the weak-form market efficiency, most researchers follow the following ideas: if a stock market's price follows a random walk model, the market will reach the weak-form market efficiency. Random walk model is a special non-stationary process. It is impossible to forecast the current condition of this random process. Because all the historical information of a weak-form market efficiency is contained in the efficient market price, investors cannot analyze historical market information through technical means to gain excess income.

This paper studies separately for SSEC and SZI whether they satisfy the weak-form market efficiency firstly.

Random walk is a special unit root process, and the random walk process is helpful to discover the cause of the fluctuation of the stock price. Therefore, the ADF method is applied to verify the property of the random walk model.

The random walk model can be represented as follows:

$$y_t = \alpha + \beta t + \rho y_{t-1} + \varepsilon_t \ , t = 1,2,\dots,n \qquad (2)$$

y_t and y_{t-1} represent the closing price at day t and day $t-1$, α is intercept, βt is time trend, ρ and β are coefficients, ε_t is random variables that obey the standard normal distribution. If $\rho = 1$,it shows that the stock price of the market obeys the random walk model, which verifies the weak-form market efficiency.

When the series is in AR (P) form, depend on whether there is an intercept and a time trend, the model can be further expressed in the following three forms:

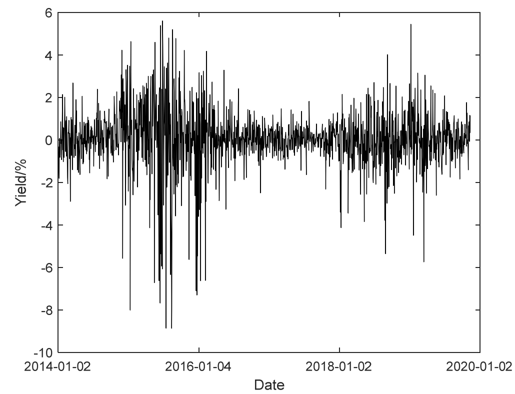
$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \qquad (3)$$

$$\Delta y_t = \alpha + \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \qquad (4)$$

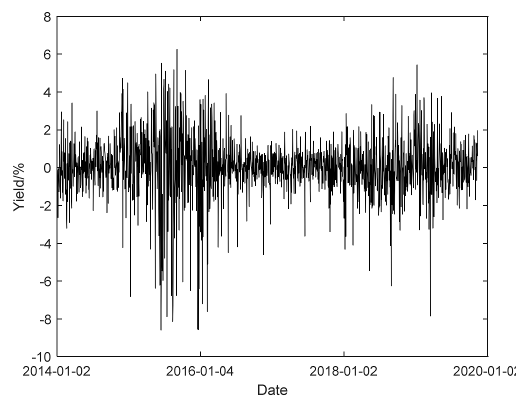
$$\Delta y_t = \alpha + \delta t + \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \qquad (5)$$

Formula (3) has no intercept and time trend, formula (4) has intercept and no time trend, and formula (5) has intercept and time trend. $\Delta y_t = y_t - y_{t-1}$, Δy_t is the first-order difference process of y_t, if Δy_t is a stable process, y_t follows the random walk model. $\sum_{i=1}^{p} \beta_i \Delta y_{t-i}$ ensure ε_t is no autocorrelation.

Generally, the image of yield time series of the stock markets can be used to judge the specific form. Yield time series of SSEC and SZI are shown in Fig. 2.



(a) SSEC



(b) SZI

Figure 2. Yield of SSEC and SZI

From Fig. 2, the yield series all oscillate around 0 and have no significant time trend or intercept, so the unit root test can be performed in the form of formula (3).The null hypothesis of ADF test is this series has a unit root , meaning this price series follows a random walk model , and the alternative hypothesis is this series has not a unit root, that is, huge profits can be obtained by analyzing historical information. This can be expressed in the following form:

$$H_0: y_t \ follow \ random \ walk$$
$$H_1: y_t \ not \ follow \ random \ walk \qquad (6)$$

2.3. Run test

Whether the stock market price follows random walk can also be tested by run test. The yield of stock markets r_t with the same symbols is recorded as a run. When $r_t >$

0 is positive run, record as '+'. When $r_t < 0$ is negative run, record as '-'. For example: The process'+++/---/++/-' has four runs.

If the number of runs is too small, it means that there is a certain time trend in the sequence, and the samples are not independent of each other. If the total number of runs is too large, there possibly has systematic short-term fluctuations that affect the observations. Both cases show that the price does not follow the random walk model. Therefore, if price follows random walk model, the number of runs cannot be too large or too small.

When the amount of data is large enough, number of runs U is approximately normal distribution, the number of runs with constant price is small, so we ignore it. Under this assumption, the average number of runs is:

$$E(U) = 1 + \frac{2n_1n_2}{N} \tag{7}$$

In the above formula, n_1 is the number of positive runs, n_2 is the number of negative runs, N is the number of days of stock markets price. The standard deviation of the number of runs is:

$$\sigma_U = \sqrt{2n_1n_2(2n_1n_2 - N)/N^2(N-1)} \tag{8}$$

Therefore, random variable Z with standard normal distribution is constructed.

$$Z = \frac{U - E(U)}{\sigma_U} \tag{9}$$

According to the existing price data of stock markets, calculate Z ,and compare it with the boundary value of standard normal distribution statistics with confidence of 0.05 ($Z_{0.025}$). If Z the following conditions are met:

$$-Z_{0.025} \leq Z \leq Z_{0.025} \tag{10}$$

We can conclude that U follows the Gaussian distribution, that is, the random walk model is established and the weak-form market efficiency is established.

2.4. Autocorrelation test

This test method is to test the correlation of time series. If a time series is independent, the autocorrelation coefficient should be infinitely close to zero. The calculation formula is:

$$\rho(k) = \frac{Cov(r_t, r_{t-1})}{\sqrt{Var(r_t)}\sqrt{Var(r_{t-1})}} = \frac{Cov(r_t, r_{t-1})}{Var(r_t)} \tag{11}$$

In the above formula, r_t is the yield of stock market, k is the lag order, $\rho(k)$ is the autocorrelation coefficient of series $\{r_t\}$.

$\rho(k)$ can be estimated in the following form:

$$\rho_k = \frac{\sum_{t=1}^{N-k}(r_t - \overline{r_N})(r_{t+k} - \overline{r_N})}{\sum_{t=1}^{N}(r_t - \overline{r_N})^2} \tag{12}$$

In the above formula, $\overline{r_N}$ is calculated as follows:

$$\overline{r_N} = \frac{1}{N}\sum_{t=1}^{N} r_t \tag{13}$$

In order to test the correlation more accurately, construct statistics $Q(k)$:

$$Q(k) = N\sum_{i=1}^{k} \rho_i^2 \sim \chi^2(k) \tag{14}$$

The boundary value of 95% confidence c was obtained by looking up the table. The hypothesis test can be expressed as follows:

$$H_0: There\ is\ no\ k-order\ correlation$$

$$H_1: There\ is\ k-order\ correlation \tag{15}$$

If $Q(k) > c$, reject the hypothesis test and the market does not reach weak-form market efficiency. Otherwise, accept the null hypothesis and the market reaches weak-form market efficiency.

2.5. Johansen cointegration test

The above method does not explore whether there is an effect between the two or not, for this reason, this paper further applies Johansen cointegration test and Granger causality test to test joint efficiency of two stock markets.

A linear combination of two non-stationary time series could be a smooth series, which is called cointegration [10]. If there is cointegration between two non-stationary processes, then this means that there is a tendency for them to co-vary over time. Cointegration is defined as follows:

K-dimensional vector $Y = (y_1, \cdots y_k)^T$ is called d, b order cointegration, recorded as $Y \sim CI(d,b)$, if satisfied:

(1)$Y \sim I(d)$, that is, each $y_i \sim I(d)$.

(2) There is non-zero vector β, makes $\beta^T Y \sim I(d-b), 0 < b \leq d$.

The Johansen cointegration test is a method of testing regression coefficients based on the VAR model, which converts the problem of finding the maximum likelihood function into a problem of finding the eigenvalue and corresponding eigenvector.

Johansen cointegration test includes two statistics: characteristic root trace (Trace statistic) and maximum characteristic root (λ_{max} statistic). The first one is selected in this paper. The critical value of the statistics has been given by Johansen. By comparing the trace statistic and the critical value, we could judge whether this hypothesis is tenable. If statistic is less than the 5% critical value, the null hypothesis is accepted.

$$H_0: There\ is\ no\ cointegration\ relation$$

$$H_1: There\ is\ cointegration\ relation \tag{16}$$

2.6. Granger causality test

Econometrics often determines whether a change in one variable affects another variable, Granger causality tests are used to test this causal relationship. The essence of this method is to test whether the lagged term of one variable can be introduced into the equation of another variable, and if one variable is affected by the lags of other variables, they are said to have Granger causal relationship [11].

Granger causal tests can only be performed on stationary time series, using Akaike Information Criterion (AIC) to determine the lag order. If p-value is less than 0.05, reject the null hypothesis.

$$H_0: A\ change\ in\ variable\ X\ cannot\ cause\ change\ in\ variable\ Y.$$
$$H_1: A\ hange\ in\ variable\ X\ can\ cause\ a\ change\ in\ variable\ Y. \tag{17}$$

3. RESULTS AND DISCUSSION

3.1. ADF test

When the p-value of ADF test is more than 0.05, there is enough certainty that the unit root exists in this time series. The results are shown in TABLE 2.

TABLE 2. RESULTS OF ADF TEST

Name	T statistic	p-value	Conclusion
SSEC	-2.3953	0.411	non-stationary
SZI	-2.5417	0.349	non-stationary

According to the results of ADF test, it is apparent that there is unit root in this time series, therefore the time series is non-stationary and it may follow the random walk model, Chinese stock market has already reached weak-form market efficiency.

3.2. KPSS test

This paper selects Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test as one supplement of the ADF test [13]. This test method is of the opposite null hypothesis compared with ADF test, that is to say, when the p-value is less than 0.05, there is a unit root in this series and it is easy to say the stock market is of weak-form market efficiency. The results are shown in TABLE 3.

TABLE 3. RESULTS OF KPSS TEST

Name	LM statistic	p-value	Conclusion
SSEC	1.7044	<0.01	non-stationary
SZI	1.8165	<0.01	non-stationary

By analyzing these results, it can be deduced that this series is non-stationary and Chinese stock market has already reached weak-form market efficiency. The results of KPSS test and those of ADF test are consistent.

3.3. PP test

The above two test methods are all based on the homoscedasticity assumption. In consideration of the condition of heteroscedasticity, Phillips-Perron (PP) test is selected by this paper to guarantee that the results of different tests are credible (Xue, Chen, 2019). PP test is of the same null hypothesis as ADF test. That is, when the p-value of PP test is more than 0.05, there is enough certainty that the unit root exists in this series. The results are as shown in TABLE 4.

By analyzing these results, it is not hard to see that the PP test gives the same results as the above two methods.

To sum up, all three tests yield consistent results, therefore, there is enough certainty that this series is non-stationary and Chinese stock market has reached weak-form market efficiency. This is the conclusion of unit root test.

TABLE 4. RESULTS OF PP TEST

Name	T statistic	p-value	Conclusion
SSEC	-8.5217	0.6344	non-stationary
SZI	-10.31	0.5346	non-stationary

3.4. Run test

The total number of days N, the number of positive runs n_1, the number of negative runs n_2, the number of runs U, the standard deviation σ_U, the average number of runs $E(U)$, the value of random variable Z and the possibility of accepting the hypothesis (p-value) were calculated by the formulas in the part D of the METHORDOLOGY. Meanwhile, for the purpose of getting more authentic results, the interval was divided into two different small intervals (totally 3 intervals) and conduct the tests respectively. The results are shown in the TABLE 5.

Compare Z statistic with $Z_{0.025}$ in every interval, the p-value is always more than 0.05 and the inequation as bellow is met all the time:

$$-Z_{0.025} \leq Z \leq Z_{0.025} \tag{18}$$

TABLE 5. RESULTS OF RUN TEST OF STOCK MARKETS

Name	Interval	N	n_1	n_2	U	σ_U	$E(U)$	Z	$Z_{0.025}$	p-value	Conclusion
SSEC	2014-2020	1465	797	668	746	18.983	727.821	0.9313	1.96	0.352	accept
	2014-2017	733	325	408	388	13.354	362.801	1.887	1.96	0.0592	accept
	2017-2020	732	343	389	359	13.465	365.555	-0.48679	1.96	0.626	accept
SZI	2014-2020	1465	759	706	748	19.106	732.541	0.7829	1.96	0.434	accept
	2014-2017	733	345	388	378	13.481	366.239	0.87242	1.96	0.383	accept
	2017-2020	732	361	371	371	13.516	366.932	0.301	1.96	0.763	accept

Hence, it's concluded that the number of runs follows the normal distribution whether partly or totally. And it means the weak-form market efficiency is established with run test method.

3.5. Autocorrelation test

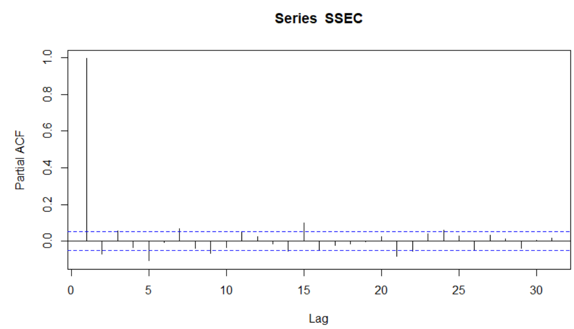
According to Fig. 2 mentioned in part *B* of METHODOLOGY, the fluctuation of the yield of SSEC and SZI is different from interval 2014-2016 to 2017-2020. Thus, further correlation analysis is required to explain the phenomenon and figure out the correlation of the yield series.

Firstly, whether the partial autocorrelation (PACF) of closing prices is truncated indicates whether the time series is autocorrelated after differencing. The plot of the PACF of the closing prices is shown in Fig. 3.

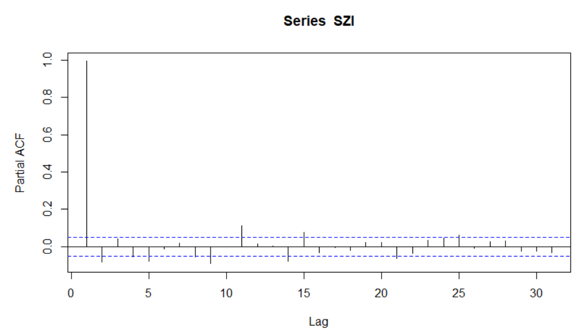
The coefficient of the PACF of the closing prices is shown in TABLE 6.

Fig. 3 and TABLE 6 show that there is basically a first order truncation of the PACF of the closing prices. So, it is necessary to carry out more detailed statistical analysis and test on the yield of SSEC and SZI which is the first difference of the closing prices.

The article conducted the autocorrelation test mentioned in part *D* of METHODOLOGY with the yield of SSEC and SZI by the R Programming Language. According to the Akaike Information Criterion (AIC), the lag order was determined as 16. The annual values of Q statistic from 2014 to 2020 are shown in TABLE 7.



(a) SSEC



(b) SZI

Figure 3. PACF of the closing prices of SSEC and SZI

TABLE 6. PACF OF THE CLOSING PRICES OF SSEC AND SZI

k	SSEC	SZI	k	SSEC	SZI
1	0.995	0.994	16	-0.052	-0.031
2	-0.071	-0.084	17	-0.023	-0.005
3	0.057	0.040	18	-0.016	-0.022
4	-0.033	-0.054	19	-0.003	0.021
5	-0.107	-0.080	20	0.026	0.024
6	-0.007	-0.013	21	-0.082	-0.063

7	0.068	0.018	22	-0.056	-0.038
8	-0.037	-0.057	23	0.042	0.034
9	-0.064	-0.092	24	0.060	0.046
10	-0.033	0.000	25	0.030	0.062
11	0.054	0.110	26	-0.047	-0.011
12	0.027	0.015	27	0.035	0.027
13	-0.014	0.005	28	0.014	0.029
14	-0.053	-0.080	29	-0.037	-0.025
15	0.101	0.076	30	0.005	-0.024

As mentioned, c is the critical value of the chi-square test. It is found that the Q statistic is almost less than c except for the Q statistic of SSEC in interval 2015-2016 and 2016-2017 and the Q statistic of SZI in interval 2015-2016, so the null hypothesis is basically accepted in interval 2014-2020 and the yields are considered to be not correlated which means Chinese stock market has reached weak-form market efficiency, and it is consistent with previous results.

TABLE 7. Q STATISTIC OF SSEC AND SZI WITH 16TH LAG ORDER

Interval	SSEC	SZI
2014-2015	31.71561	17.9479
2015-2016	41.76026	38.53402
2016-2017	48.35624	30.98223
2017-2018	9.238255	17.91725
2018-2019	23.97769	17.68382
2019-2020	11.00271	10.12726

3.6. Johansen cointegration test

According to the outcomes of unit root test, the closing prices series of SSEC and SZI are non-stationary unit root series. Before doing the Johansen cointegration test, the order of integration of the non-stationary time series should be same. Hence, it is indispensable to do the ADF test of the yield of SSEC and SZI which is the first difference of the closing prices. The results are shown in TABLE 8.

TABLE 8. RESULTS OF ADF TEST OF THE YIELD

Name	T statistic	p-value	Conclusion
SSEC	-10.933	<0.01	stationary
SZI	-10.929	<0.01	stationary

In TABLE 8, the first difference of the closing prices of SSEC and SZI are both stationary, which indicates that the closing prices series of SSEC and SZI are both integration of order one. Therefore, Johnsen cointegration test can be carried on with the data of the closing prices to find out whether the Shanghai and Shenzhen stock markets have the tendency of linkage. The results are shown in TABLE 9.

TABLE 9. RESULTS OF JOHANSEN COINTEGRATION TEST

Null hypothesis	Eigenvalue(lambda)	Trace statistic	5% critical value	Decision
0 cointegration vector	0.007614	16.58	17.95	accept
at most 1 cointegration vector	0.003684111	5.4	8.18	accept

According to TABLE 9., the trace statistic is both less than 5% critical value. Therefore, the decision is to accept the null hypothesis and there is no cointegration relation between SSEC and SZI. Meanwhile, the result shows that there is no long-term cointegration between the price levels of the stock market in Shanghai and Shenzhen.

3.7. Granger causality test

The time series of the Granger causality test must be stationary, so the article take the unit root test with the yield of SSEC and SZI firstly. As can be seen in TABLE 8, the yield series is stationary, so the precondition of the causal test for the sample is satisfied.

The result of the causality test is depended on the lag order which is determined by Akaike Information Criterion (AIC) as 35. The results are shown in TABLE 10.

By TABLE 10, the decision is to reject the null hypothesis which means the yield of SSEC and SZI are Granger-cause mutually. In other words, the previous information about the yield of SSEC (SZI) which is included in the forecast about the future yield of SZI (SSEC) is better than that which is only included in the historical data about the yield of SZI (SSEC).

TABLE 10. RESULTS OF GRANGER CAUSALITY TEST

Null hypothesis	F statistic	p-value	Decision
SSEC do not Granger-cause SZI	1.5104	0.03513	reject
SZI do not Granger-cause SSEC	2.8973	<0.001	reject

To sum up, although the closing price of Shanghai and Shenzhen Composite Index has no long-term cointegration relation, the daily yield of Shanghai and Shenzhen Composite Index can predict each other in some degree which means there must be some relations between them somehow. Therefore, the article got the conclusion that the Shanghai and Shenzhen stock markets has not reached the joint weak-form market efficiency yet.

4. CONCLUSION

Through the empirical analysis of the closing price of SSEC and SZI, this study concludes that Chinese stock market has already reached weak-form market efficiency but Shanghai and Shenzhen stock markets has not attained the joint weak-form market efficiency. Since the above analysis is the tests of SSEC and SZI, it does not mean that any stock in the Shanghai Stock Exchange or the Shenzhen Stock Exchange reaches the weak-form market efficiency and it is possible that some stocks does not accord with the conclusion.

Unit root tests, run test and autocorrelation test are employed to test the efficiency in this paper and all three tests yield consistent results that both Shanghai and Shenzhen stock markets basically reach weak-form market efficiency. However, accepting that the stock prices are unpredictable does not mean that investing in the stock market is a gamble. In the stock market, it makes no sense to gamble because the weak-form market efficiency means it is a fair bet. In other words, the odds of winning the lottery are just luck. If the attempt continues to infinity, the average of wins ends up being zero.

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