

Have financial market prices become more informationally efficient?

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The research aims to investigate the change in informational efficiency of the US stock market from 1926 to 2021. The degree of informational efficiency is quantified using the variance ratio test. The paper analyzed the change in informational efficiency after major market regulation policies have been implemented (e.g. Dodd-Frank Act and MiFID II). In general, the informational efficiency of the US stock market has improved. This also sheds light on the effectiveness of multiple policies that aim to improve the informational efficiency of the US market.

Introduction

In 1965, economist Eugene Fama proposed the efficient market hypothesis¹. In general terms, the concept assumes the market price at any time to fully reflect all available information for resource allocation^{2,3}. Since the proposal of the efficient market hypothesis, the financial market has greatly changed⁴. The cost and availability of information have vastly decreased for investors. The cost of trading and liquidity of assets also improved greatly compared to previously⁵. Furthermore, with the increase in the number of institutional investors⁶, the rate and spending on price discovery have also increased^{7,8}. While trading information has become more accessible⁹ whether the change has brought the market closer to Fama's ideal remains a question that needs to be answered. Therefore in this paper, the question "Have financial market prices become more informationally efficient?" will be examined using the US stock exchange data.

This paper hypothesizes that given the legislative change to the US stock market, the decision of the investors should become more informed and thus a more informationally efficient market compared to before. With varying approaches toward quantifying informational efficiency, there is no consensus¹⁰. In this research, this paper quantifies the informational efficiency of the stock market by applying a variance ratio test to the US stock market return data from 1926 to 2021. The variance ratio test is carried out in separate time spans that are arranged according to major policy implementations in the stock market. By doing so, the effectiveness of the policy in improving informational efficiency can be more visible, and specific characteristics that led to its success can be identified.

The results from the statistics resemble an upward trend of informational efficiency, suggesting that the technological improvements and legislative changes have brought the stock market closer to Fama's ideal model. The underlying reason for the change in informational efficiency is also provided in

the paper. In addition, the paper also makes recommendations on how policy can be designed to be more effective at improving informational efficiency.

Methodology

The analysis will be carried out using the US stock market data from 1926 to 2021 recorded daily. The data includes the market return, small minus big, and high minus low of the stock market. The stock market return data is obtained from the website of Kenneth French¹¹.

The changes to informational efficiency in the US stock market will be measured using the variance ratio test. Following Fama's market efficiency model, the price of any assets in a given time should reflect all information present. This presents consecutive changes to hold no correlation with each other, deducing that the price should resemble a random walk. Under the assumption that stock price is a random walk, the variance ratio between consecutive returns should be 1. Therefore the closer the statistics derived from the realized stock data is to 1, the more informationally efficient the stock market is¹².

The variance ratio test is also used for its advantages. Notably, it relies on very fundamental data such as market return which bypasses the limited data availability for older firms and expands the time span of the data available to the research. The method is also easily replicable and comparable when used on different stock markets.

The derivation of the variance ratio test formula is provided below.

There is a distribution of daily stock market returns. There is a sample of N daily observations. (Realization)

$$R_{mean} = \frac{1}{N} \sum_{i=1}^N r_i \quad (1)$$

Table 1 Summary statistics of two-day time span. This table presents summary statistics for the standard deviation of two consecutive day returns, the standard deviation of single-day returns, and the deduced correlation coefficient between the return of consecutive days. Time periods are divided equally from 1926 to 2021, inclusive.

Time period	Standard deviation of two consecutive day return $[R_t + R_{t+1}]$	Standard deviation of single-day return $V [R_t]$	Result $\frac{2V [R_t]}{V [R_t + R_{t+1}]}$
1926-1945	2.2	1.51	0.94
1946-1964	1.03	0.68	0.87
1965-1983	1.23	0.78	0.80
1984-2002	1.44	1.11	1.19
2003-2021	1.63	1.2	1.13

Table 2 Summary statistics of five-day time span. This table presents summary statistics for the standard deviation of five consecutive day returns, the standard deviation of single-day returns, and the deduced correlation coefficient between the return of consecutive days. Time periods are divided equally from 1926 to 2021, inclusive.

Time period	Standard deviation of two consecutive day return $[R_t + R_{t+1}]$	Standard deviation of single-day return $V [R_t]$	Result $\frac{2V [R_t]}{V [R_t + R_{t+1}]}$
1926-1945	3.5	1.51	0.93
1946-1964	1.61	0.68	0.89
1965-1983	2.11	0.78	0.68
1984-2002	2.27	1.11	1.19
2003-2021	2.08	1.23	1.73

Its variance: (random variable)

$$V = [R_{mean}] = V \left[\frac{1}{N} \sum_{i=1}^N R_i \right] \quad (2)$$

$$\frac{1}{N} V [r] \quad (3)$$

(if daily stock returns are independent)

If daily stock returns are not correlated with each other ($Cov(\epsilon_t, \epsilon_{t+1}) = 0$), then:

$$R_t + R_{t+1} \propto N(2\mu, 2\sigma^2) \quad (7)$$

The statistics:

$$t^2 = \frac{2V [R_t]}{V [R_t + R_{t+1}]} = 1 \quad (8)$$

1 Variance ratio test

Assuming that daily stock market returns follow the process (t is an index for time):

$$R_t = \mu + \epsilon_t \quad (4)$$

$$R_t \propto N(\mu, \sigma^2) \quad (5)$$

Then the sum of two consecutive daily stock returns is:

$$R_t + R_{t+1} = (\mu + \epsilon_t) + (\mu + \epsilon_{t+1}) = 2\mu + \epsilon_t + \epsilon_{t+1} \quad (6)$$

The value derived from the equation is displayed in the table below. Two-time spans are examined, a two-day time span to evaluate the correlation, and a five-day time span to simulate a trading week. The test is replicable following the steps above using any stock return data.

The initial statistics resembled an inconsistent trend that is not very informative in answering the question. Therefore winsorization is applied to the stock return data to remove the anomalies. The processed results after winterization are shown in the two tables below.

To better answer the research question, the time period is rearranged according to changes to the stock market that are

Table 3 Summary statistics of two-day time span after winsorization. This table presents summary statistics for the standard deviation of two consecutive day returns, the standard deviation of single-day returns, and the deduced correlation coefficient between the return of consecutive days. Time periods are divided equally from 1926 to 2021, inclusive. All variables are winsorized at the 5th and 95th percentile values.

Time period	Standard deviation of two consecutive day return $[R_t + R_{t+1}]$	Standard deviation of single-day return $V [R_t]$	Result $\frac{2V [R_t]}{V [R_t + R_{t+1}]}$
1926-1945	1.75	1.20	0.95
1946-1964	1.00	0.65	0.86
1965-1983	1.20	0.76	0.80
1984-2002	1.32	0.76	0.67
2003-2021	1.44	0.76	0.56

Table 4 Summary statistics of five-day time span after winsorization. This table presents summary statistics for the standard deviation of five consecutive day returns, the standard deviation of single-day returns, and the deduced correlation coefficient between the return of consecutive days. Time periods are divided equally from 1926 to 2021, inclusive. All variables are winsorized at the 5th and 95th percentile values.

Time period	Standard deviation of two consecutive day return $[R_t + R_{t+1}]$	Standard deviation of single-day return $V [R_t]$	Result $\frac{2V [R_t]}{V [R_t + R_{t+1}]}$
1926-1945	2.82	1.20	0.91
1946-1964	1.57	0.65	0.87
1965-1983	2.05	0.76	0.69
1984-2002	2.09	0.76	0.66
2003-2021	2.23	0.76	0.58

assumed to have influence to informational efficiency such as legislative change and technological improvements. The data used is winsorized. The reason for rearranging to the time period is to better detect the change in informational efficiency. By arranging the time periods of the variance ratio test such that each statistics reflects the influence of the newly implemented legislation or change in information dissemination, the change in informational efficiency becomes more apparent. Specific justification and explanation for the time period choice are found in the appendix.

2 Results

As suggested by the variance ratio test, if the stock market is informationally efficient, the statistics result should be 1. Thereby by measuring the absolute value of the variance ratio test result's difference to 1, the informational efficiency of different time periods can be compared. The smaller the absolute value difference, the more informationally efficient the market

is.

The absolute value is shown in the table below and presented in the following graphs.

As shown, the result of the variance ratio test has deviated significantly from 1 during the period from 1940-2009 and returned to a low level afterward with a slight increase. The decreasing absolute value difference suggests that the market has been approaching a more informationally efficient state, verifying the hypothesis. The linearized data has indicated a consistent trend of decrease suggesting the market has been becoming more informationally efficient since 1926 to now.

3 Discussion

The variance ratio test suggests that the US stock market has improved in terms of informational efficiency, but further research needs to be carried out before the hypothesis can be verified. This may also suggest that the legislation on the market has been effective in improving the informational efficiency of

Table 5 Summary statistics of two-day time span after rearrangement. This table presents summary statistics for the standard deviation of two consecutive day returns, the standard deviation of single-day returns, and the deduced correlation coefficient between the return of consecutive days. Time periods between 1926 to 2021 inclusive are rearranged according to major market regulation changes. All variables are winsorized at the 5th and 95th percentile values.

Time period	Standard deviation of two consecutive day return $[R_t + R_{t+1}]$	Standard deviation of single-day return $V [R_t]$	Result $\frac{2V [R_t]}{V [R_t + R_{t+1}]}$
1926-1945	1.87	1.29	0.95
1946-1964	1.13	0.74	0.85
1965-1983	1.66	1.19	1.03
1984-2002	1.37	0.98	1.02
2003-2021	1.31	0.97	1.09

Table 6 Summary statistics of five-day time span after rearrangement. This table presents summary statistics for the standard deviation of five consecutive day returns, the standard deviation of single-day returns, and the deduced correlation coefficient between the return of consecutive days. Time periods between 1926 to 2021 inclusive are rearranged according to major market regulation changes. All variables are winsorized at the 5th and 95th percentile values.

Time period	Standard deviation of two consecutive day return $[R_t + R_{t+1}]$	Standard deviation of single-day return $V [R_t]$	Result $\frac{2V [R_t]}{V [R_t + R_{t+1}]}$
1926-1945	3.02	1.29	0.91
1946-1964	1.86	0.74	0.79
1965-1983	2.56	1.19	1.09
1984-2002	2.10	0.98	1.09
2003-2021	2.04	0.97	1.12

the market. However, the trend is inconsistent, and the theory holds many controversies which will be further discussed.

A few limitations are present in this study. First, variables such as information and factors that influence the stock market are difficult to quantify. A relationship such as a correlation and causal is hard to distinguish and quantify inaccurate numbers. The research is also limited by the data range. Stock markets prior to 1926 could have been equally or more informationally efficient yet there is no data recording market return during that period.

The nature of the variance ratio test also holds limitations. For example, the theory is built on the controversial assumption that the stock market follows a random walk which may only hold true in the theoretical model. For example, institutional investors separate larger trades, so the market does not efficiently update its prices to current information. This also causes the price in two consecutive time periods to be correlated. This disobeys the investor's behavior variance ratio test assumes. Furthermore, phenomena such as momentum buy-

ing, and the irrational nature of investors also distort the theoretical model that the variance ratio tests assume. Therefore, the variance ratio test may be fundamentally flawed.

Lastly, as indicated by the variance ratio test, it is possible that market regulation enacted between the 1999 to 2009 improved informational efficiency. Taking major reforms such as Regulation Fair Disclosure in 2000 and Sarbanes-Oxley Act in 2002 which saw a significant improvement in informational efficiency, some direction for future policies could be outlined. One is to pressure more frequent and transparent report that reduces the chance of fraud in listed companies and the other is to ensure that investors compete in a fair environment where there is no selective disclosure, in which some investors received market-moving information before others and were allowed to trade on it. The reason that the research cannot confidently verify the hypothesis is because the conclusions are based on a limited set of data aggregated over a large time periods. This also stops the research from pinpointing specific policies that is the most effective in improving informational

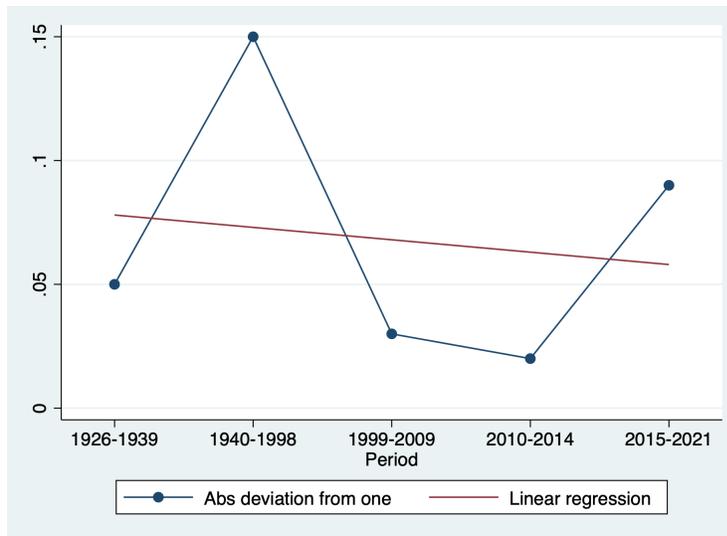


Fig. 1 Graph of the absolute value from 1 for two-day time span. This figure visualizes the result from table 7. The smaller the absolute value difference, the more informational efficient the market is.

Table 7 Absolute value of statistics result of two-day time span. This table presents summary statistics for the deviation of the result from the efficient market hypothesis for the two-day time span. All results are presented in absolute value for clearer reading. Time periods between 1926 to 2021 inclusive are rearranged according to major market regulation changes.

Time period	Result	Absolute value
1926-1939	0.95	0.05
1940-1998	0.85	0.15
1999-2009	1.03	0.03
2010-2014	1.02	0.02
2015-2021	1.09	0.09

efficiency however it does provide a time frame to look for.

4 Conclusion

In this paper, the change in informational efficiency has been evaluated through the variance ratio test with regard to major market regulation policies. The results are based on the statistics formulated from the variance ratio test chosen for its suitability of available data and its easily replicable procedure that could generate results of other stock markets for comparison. To clearly detect the change in informational efficiency after policy implementation, the time period for the variance ratio test is readjusted to fit the policy enactment dates. This not only permitted easier data analysis but also provided insights into the specific characteristics of a policy that would make it effective in improving the informational efficiency of the stock market.

In general, informational efficiency has improved in the US

stock market. The varying degree of change in informational efficiency suggests that the different market policy holds different effectiveness. Policies between the period of 1999 to 2009 created significant improvements in the informational efficiency of the US stock market. This suggests that policies push for more frequent and transparent reports of companies and suppress selective disclosure that can effectively improve the dissemination of information in the stock market. This provides a goal for future policies to be orientated towards. Given that there is evidence for the effectiveness of these policies, it is recommended that other countries incorporate such policies to improve the informational efficiency of their stock markets. Future research could use the variance ratio test to examine other stock markets in regard to major market regulations and carry out cross-comparison with the US stock market. Such comparisons could yield more insights into the characteristics of an effective policy in improving informational efficiency in the stock market.

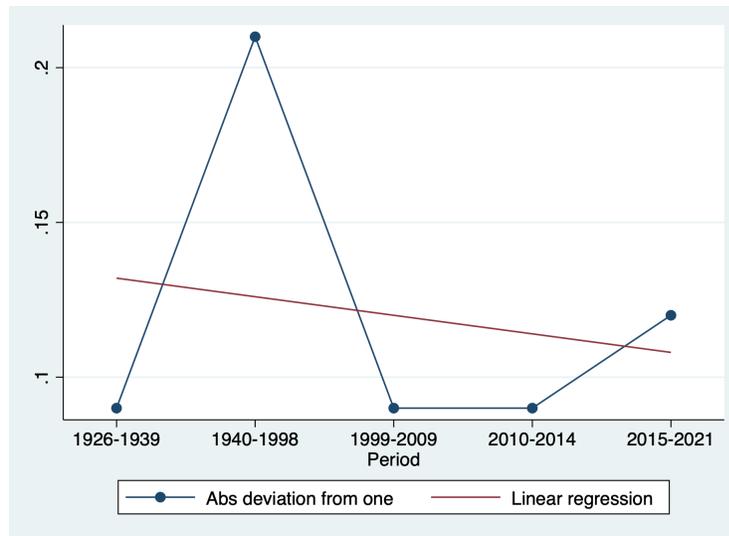


Fig. 2 Graph of the absolute value from 1 for five-day time span. This figure visualizes the result from table 8. The smaller the absolute value difference, the more informational efficient the market is.

Table 8 Absolute value of statistics result of five-day time span. This table presents summary statistics for the deviation of the result from the efficient market hypothesis for the five-day time span. All results are presented in absolute value for clearer reading. Time periods between 1926 to 2021 inclusive are rearranged according to major market regulation changes.

Time period	Result	Absolute value
1926-1939	0.91	0.09
1940-1998	0.79	0.21
1999-2009	1.09	0.09
2010-2014	1.09	0.09
2015-2021	1.12	0.12

References

- 1 E. Fama, *Journal of financial economics*, **49**, 283–306.
- 2 Q. Chen, I. Goldstein and W. Jiang, *Review of Financial Studies*, **20**, 619–650.
- 3 S. Grossman and J. Stiglitz, *The American economic review*, **70**, 393–408.
- 4 A. Kyle, *Econometrica: Journal of the Econometric Society*, 1315–1335.
- 5 B. Bennett, R. Stulz and Z. Wang, *Does the stock market make firms more productive?*, <https://doi.org/10.3386/w24102>.
- 6 E. Kelley and E. Boehmer, *SSRN Electronic Journal*.
- 7 O. Dessaint, T. Foucault, L. Frésard and A. Matray, *The Review of Financial Studies*, **32**, 2625–2672.
- 8 B. Weller, *The Review of Financial Studies*, **31**, 2184–2226.
- 9 A. Edmans, I. Goldstein and W. Jiang, *The Journal of Finance*, **67**, 933–971.
- 10 R. Roll, *The Journal of Finance*, **43**, 541–566.
- 11 R. Kenneth, *French - data library*, http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html, Retrieved July 16, 2022, from.
- 12 A. W. Lo and A. C. MacKinlay, *The review of financial studies*, 1988, **1**, 41–66.

Appendix

Justification for the time periods

The reason for rearranging to the time period is to better detect the change in informational efficiency. By arranging the time periods of the variance ratio test such that each statistic reflects the influence of the newly implemented legislation or change in information dissemination, the change in informational efficiency becomes more apparent. Specific justification and explanation for the time period choice are proved below.

1926-1939

The first variance ratio test of 1926 to 1939 is set such that the statistics derived from this period's data can be compared with the statistics after the Investment Company Act of 1940 is implemented.

1940-1998

In 1940, the Investment Company Act of 1940 is implemented. The Act regulates the organization of companies, including mutual funds, that engage primarily in investing, reinvesting, and trading in securities, and whose own securities are offered to the investing public. The regulation is designed to minimize conflicts of interest that arise in these complex operations. The Act requires these companies to disclose their financial condition and investment policies to investors when stock is initially sold and, subsequently, on a regular basis. The focus of this Act is on disclosure to the investing public of information about the fund and its investment objectives, as well as on investment company structure and operations.

The legislation provided greater transparency, reducing fraud and manipulation in the market. Thereby, the disclosed company financial details should make investors more informed and subsequently, a more informationally efficient stock market. Therefore the time period 1940-1998 is subjected to these policies.

1999-2009

In 2000, the Regulation Fair Disclosure was passed. It sought to stamp out selective disclosure, in which some investors received market-moving information before others, and were allowed to trade on it. In 2002, the Sarbanes-Oxley Act was passed by Congress in response to widespread corporate fraud and failures. The act implemented new rules for corporations, such as setting new auditor standards to reduce conflicts of interest and transferring responsibility for the complete and accurate handling of financial reports.

The two legislation makes information more transparent to retail investors and reduces the delay of information dissemination to retail information. Therefore, theoretically, the price level at a given time should encompass more market information than before and thus be more informationally efficient. Therefore the time period 1999-2009 is dedicated to these two policies.

2010-2014

In 2010, the Dodd-Frank Wall Street Reform and Consumer Protection Act was implemented after the financial crash in 2008. The Act improved financial stability, and credit rating credibility and restricted banks' investment. This provides more information for both institutional investors and retail investors before making investments thereby improving the informativeness of their purchase in the market. Thereby the time period 2010-2014 is dedicated to these two policies.

2015-2021

Though Directive 2014/65/EU, known as MiFID II is enacted in Europe, many of its requirements on companies spread to companies enlisted on the US stock market. MiFID II ensures fairer, safer, and more efficient markets and

facilitates greater transparency for all participants. New reporting requirements and tests increase the amount of information available and reduce the use of dark pools and OTC trading. The rules governing high-frequency trading impose a strict set of organizational requirements on investment firms and trading venues, and the provisions regulating the non-discriminatory access to central counterparties (CCPs), trading venues, and benchmarks are designed to increase competition. The protection of investors is strengthened through the introduction of new requirements on product governance and independent investment advice, the extension of existing rules to structured deposits, and the improvement of requirements in several areas, including the responsibility of management bodies, inducements, information and reporting to clients, cross-selling, remuneration of staff, and best execution. Thereby the last time period is dedicated to 2015-2021.