An Empirical Re-Examination of the Weak Form Efficient Markets Hypothesis of the Ghana Stock Market Using Variance-Ratios Tests

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Abstract

This study empirically re-examines the weak form efficient markets hypothesis of the Ghana Stock Market using a new robust non-parametric variance-ratios test in addition to its parametric alternative. The main finding is that stock returns are conclusively not efficient in the weak form, neither from the perspective of the strict random walk nor in the relaxed martingale difference sequence sense. Unlike previous evidence, our finding is robust to thin-trading, sub-sample periods as well as the choice of dataset. Consistent with prior studies, the results of the parametric variance-ratios test are ambiguous. By contrast, its non-parametric alternative provides conclusive results.

Keywords: Weak form efficiency, Random walk, Martingale difference sequence, Parametric and non-parametric variance-ratios tests, Ghana stock market

1. INTRODUCTION

A well-functioning financial system in developing African countries has been seen in recent times as crucial to their economic development[1] (e.g., Magnusson and Wydick, 2002). Developing a formal capital market is viewed in this case as critical to the proper running of such a system. The UNDP 2003 Report shows, for example, that the number of stock markets in Africa increased from 10 to 18 during the last decade. With increasing importance of emerging African markets both in size and number, the need for reliable evidence on their informational efficiencies is of paramount interest to investors, regulators, and academics alike. However, while there are a small number of prior empirical studies analysing African stock markets, their conclusions as to the predictability of future stock returns based on past prices have been mixed. Dickinson and Muragu (1994) provide evidence which shows, for example, that the Kenyan market is weak form efficient, in contrast to the results of Parkinson (1984). Apart from the general mixed evidence, a central feature is that most of the existing studies are conducted through the use of conventional weak form testing techniques such as serial correlation tests, whose robustness have been questioned elsewhere (e.g., Hsieh, 1991).

The Ghana Stock Exchange (GSE) has been in operation since November 1990. Osei (1998) and Dewotor and Gborglah (2004) have investigated the weak form efficiency in the price series of a number of listed stocks. Their results rejected the notion of weak form market efficiency in Ghana. While these studies do not clearly state the version of the weak form market efficiency that is rejected, none adjusts for thin-trading. Crucially, the use of serial correlation test, whose robustness has been questioned

[1]It is worth reminding that there are some disagreements within the financial development economics literature (e.g., Arestis and Demetriades, 1993; Levine and Zervos, 1996; Levine, 1997), as to the direction of causality between financial development and economic development.

elsewhere (e.g., Hsieh, 1991), is a striking feature, raising substantial doubts as to whether these results will hold in the face of an empirically well-specified methodology like the Lo and MacKinlay (1988, 1989) parametric variance-ratios test. A more compelling basis is provided by Wright (2000), who proposes the use of a non-parametric variance-ratios test to examine the weak form market efficiency. He reports that it is well-specified, and more powerful in detecting violations of the hypothesis, than its parametric alternative. Recent applications by Belaire-Franch and Opong (2005a and b), and Chang et al. (2006) provide evidence, which is significantly consistent with that of Wright (2000). Additionally, market microstructure theory suggests that increases in market capitalisation and membership, among others, lead to improvements in trading efficiency (e.g., Amihud et al., 1997). And, as we demonstrate later, there have been considerable developments in the Ghanaian market. Accordingly, it can be conjectured that there should be commensurate improvements in market efficiency, even if earlier studies did not suffer from methodological weaknesses, '*ceteris paribus*'.

This study seeks to empirically re-examine the weak form market efficiency evidence on Ghana. In doing so, it makes significant contributions to the extant literature. Firstly, it follows an empirically robust Wright's (2000) non-parametric variance-ratios test as well as adjusts for thin-trading. A significant innovation in this is that to the best of our knowledge, this will be the first replication of Wright's test within an African market context. Secondly, unlike prior studies that offer evidence by analysing only the price series of a sample of individual stocks, this study provides conclusive evidence using a sample of individual stocks as well as the price series of the all share market index with two crucial methodological implications for future researchers. Thirdly, it extends the existing evidence by using recently available data. Finally, unlike existing studies, it unambiguously investigates the strict random walk (RW), and the relaxed martingale difference sequence (MDS) hypotheses of the weak form market efficiency. The remainder of the paper is organised as follows. Section 2 reviews some of the previous African weak form efficiency studies. Section 3 describes the data and research methodology. Section 4 presents empirical results while section 5 concludes.

2. PREVIOUS AFRICAN STUDIES

Unlike the semi-strong form of market efficiency test, the weak form has received modest attention among professionals and academics in emerging African equity markets. While some have analysed single markets (e.g., Samuels and Yacout, 1981; Parkinson, 1984; Ayadi, 1984; Dickinson and Muragu, 1994; Osei, 1998; Olowe, 1999; Mecagni and Sourial, 1999; Asal, 2000; Adelegan, 2004; Dewotor and Gborglah, 2004), others have focused on a group of countries (e.g., Claessens et al., 1995; Magnusson and Wydick, 2002; Smith et al., 2002; Appiah-Kusi and Menya, 2003; Simons and Laryea, 2004; Jefferis and Smith, 2005). Also, while due to known relative regulatory, institutional, and infrastructural weaknesses (e.g., Appiah-Kusi and Menyah, 2003), it may be surprising especially in the face of conventional efficient markets wisdom (e.g., Fama, 1965, 1970), that evidence of random walk is found in some of these markets, it is equally instructive to point out that application of traditional weak form testing techniques known not to be well-specified (e.g., Lo and MacKinlay, 1988), is a central feature.

Samuels and Yacout (1981) and Parkinson (1984) are among the first to use serial correlation tests to examine the weak form efficiency in Africa, albeit they provide contradictory evidence. While the results of Samuels and Yacout accept the notion of weak form market efficiency in weekly price series of 21 listed Nigerian firms from 1977 to 1979, that of Parkinson reject it in monthly price series of 30 listed Kenyan firms from 1974 to 1978. Dickinson and Muragu (1994) apply run and serial correlation tests to investigate whether weekly stock price behaviour of 30 listed companies on the Nairobi Stock Exchange are weak form efficient from 1979 to 1988. In contrast to the evidence of Parkinson (1984), their results demonstrate that successive price changes are independent of each other for the majority of the companies investigated.

By contrast, Magnusson and Wydick (2002) utilise a partial autocorrelation technique to investigate monthly price behaviour of eight African stock market indices including Ghana, in comparison with nine Asian and Latin American markets from 1989 to 1998. They report that six out of the eight examined African stock market indices pass the basic weak form efficiency test. Of relevance to our study, the Ghana stock market index fails both the strict, and the relaxed versions of the weak form hypotheses. Smith et al. (2002) and Jefferis and Smith (2005) have also analysed the price behaviour of a group of African stock market indices. The two studies are unique in their application of empirically robust techniques. While Smith et al. (2002) apply Chow and Denning's (1993) multiple variance-ratios test to investigate the weak form in weekly stock market index series from 1990 to 1998 of eight African countries excluding Ghana, Jefferis and Smith (2005) use a GARCH model to detect serial dependence in weekly equity indices of the same group of countries from 1990 to 2001. Apart from South Africa, their results reject the notion of weak form efficiency in all the analysed markets.

In 2003, Appiah-Kusi and Menya apply an EGARCH-M model to examine the weak form efficiency in weekly price series of eleven African stock market indices. Their results confirm previous evidence that equity indices in Egypt, Kenya, Morocco, Mauritius, and Zimbabwe are weak form efficient, while those of Botswana, Ghana, Ivory Coast, Nigeria, South Africa, and Swaziland are not efficient. Finally, Simons and Laryea (2004) investigate the efficiency of four stock market indices from Ghana, Egypt, Mauritius and South Africa from 1990 to 2003, applying serial correlation, run, and the multiple variance-ratios tests. In congruence with previous studies, their results indicate that apart from South Africa, the index price behaviour of the markets analysed was weak form inefficient. Next, we provide a brief overview of the Ghana Stock Market.

2.1 A Brief Overview of the Ghana Stock Exchange (GSE)

Even though the idea of setting up a capital market in Ghana dates as far back as 1968 (e.g., Pearl Report, 1968; the Stock Exchange Act of 1971, Act 384), it did not materialise until the late 1980s mainly due to lack of stable political and economic environment. As part of the World Bank and IMF backed Economic Recovery Programme (ERP), the GSE was incorporated in July 1989, but officially commenced operations on 12th November 1990 with 3 brokerage firms and 11 listed firms. Table 1 provides some market development statistics from 1992 to 2001.

Table 1: Some Market Developments Statistics on the Ghana Stock Exchange (GSE)

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Volume Traded(m):	71.09	73.09	93.04	55.84	35.75	125.63	91.45	89.26	85.66	94.34
Value Traded (US$m):	5	7	75	22	17	49	60	25	10	11
GSE Index (Nov. 1990 =100):	79	171	372	298	361	512	868	736	858	956
No. of Listed Firms:	15	15	17	19	21	22	22	24	24	28
Market Cap.(US$m):	84	118	1,873	1,649	1,492	1,138	1,384	916	502	528

Source: Compiled from the African Stock Markets Handbook, UNDP (2003)

It shows that the number of listed firms, market capitalisation, the All Share Index (ASI), volume and value of shares traded, have all witnessed significant improvements. The number of listed companies, for instance, has increased consistently from a modest of 11 in 1990 to 28 by 2001. Market capitalisation has similarly increased, hitting close to US$2bn in 1994 even though this was largely due to the listing of Ashanti Goldfields Corporation in 1994. The value of shares traded also experienced close to 1000% annual increase in 1994 while the volume of shares traded reached some 125 million in 1997. On the other hand, general bearish market performance coupled with the subsequent de-listing of Ashanti to make way for its merger with Anglogold Plc in 2004, account for the significant reductions in market capitalisation in 2000 and 2001.

As has been discussed, Osei (1998) and Dewotor and Gborglah (2004) in addition to Magnusson and Wydick (2002), Appiah-Kusi and Menya (2003), and Simons and Laryea (2004) have examined the level of weak form efficiency of prices on the GSE. However, while all these studies have been unanimous on the basis of their results in arguing that price behaviour on the GSE is weak form inefficient, with the exception of Appiah-Kusi and Menya (2003), application of conventional techniques is common. Crucially, despite the recent evidence by Mlambo and Biekpe (2005) that thin-trading is an extensive problem among African markets including Ghana, existing studies fail to adjust for thin-trading. Similarly, in spite of the considerable market microstructure changes in terms of market capitalisation, membership, value and volume of shares traded over time, none of the above studies demonstrates the robustness of its evidence over sub-sample periods. Further, all the above studies have examined the weak form efficiency using either the all share market index, or a sample of individual listed stocks.

However, while examination of the index series, for example, will provide evidence to reflect the impact of regulatory and market microstructure changes in the market as a whole, analysis of a sample of individual listed stocks' price series will reveal the effects of such similar changes in each stock over time.

This study differs from prior papers in several ways. Firstly, it applies recently developed robust non-parametric variance-ratios test for the first time within an emerging African market context. Secondly, in response to recent evidence (e.g., Mlambo and Biekpe, 2005), we adjust for thin-trading. Thirdly, the analysis is carried over the full sample period as well as three sub-sample periods with the view to ascertaining whether probable regulatory and market microstructure changes do lead to similar improvements in market efficiency over time. Finally, this study overcomes a key weakness in prior studies by carrying out a comprehensive analysis of the price series of the all share market index as well as a sample of individual listed companies. Unlike existing studies, this approach ensures a conclusive evaluation of the degree of weak form efficiency of both the market index and the individual listed stocks.

3. DATA AND RESEARCH METHODOLOGY

3.1 Data

Two types of data were collected from Databank, a brokerage firm in Ghana. The first consists of daily closing GSE All Share Index (ASI) price series. The ASI is a value-weighted index made up of all listed stocks on the GSE. The period under consideration for the ASI begins from its original base of 12th November 1990, and ends on 31st December 2005. This yields a total of 2,138 time series observations. The daily closing stock price series of individual listed stocks constitutes the second category of data used.

For powerful computations, only 20 stocks, which had at least 1,000 daily price series observations, were analysed. This ranges from a maximum of 2,138 observations for the 11 founding stocks to a minimum of 1,026 observations with an average of 1,854 observations per stock. Appendix 1 fully defines the names of stocks as well as displays sectoral distribution of sampled stocks.

3.2 Return Computation, Thin Trading and Market Efficiency

Daily returns for the All Share Index (ASI) and individual stocks are computed as follows:

$$R_t = Ln(P_t) - Ln(P_{t-1}) \tag{1}$$

Where R_t = Daily return for the ASI or stock for period *t*, P_t = Daily ASI or stock price for period *t*, P_{t-1} = Daily ASI or stock price for period $t-1$, and Ln = Natural logarithm.

A key assumption underpinning (1) is that stock returns are not only log-normal, but also are traded on a continuous basis. Unfortunately, this assumption will not hold if shares are subject to thin-trading. A large number of papers (e.g., Fisher, 1966; Scholes and Williams, 1977; Dimson, 1979; Miller et al., 1994; Mlambo and Biekpe, 2005), have examined the impact of thin-trading on studies of market efficiency. An empirical consensus from these papers is that thin-trading introduces spurious autocorrelation into stock price series, which results in false rejection of the independence hypothesis.

Several methods for correcting thin-trading have been proposed (e.g., Dimson, 1979; Cohen et al., 1983; Fowler and Rorke, 1983; Stoll and Whaley, 1990). However, the method suggested by Scholes and Williams (1977) is adopted because it offered more robust results than alternative methods. The method assumes that although trades are infrequent, a transaction takes place in every measurement interval, and price-adjustment delays arise only through infrequent trading so that an observed transaction price is the true price at the time of the transaction. Specifically, computed thinly-traded returns were corrected by regressing returns on individual stocks against the returns on the corresponding market index from the lag, current, and lead periods, which is divided by one plus twice the estimated autocorrelation coefficient for the market index.

3.3 The Random Walk and the Martingale Difference Sequence Hypotheses

The strict random walk (RW) and the relaxed martingale difference sequence (MDS) hypotheses of the weak form market efficiency are tested. The random walk (RW) hypothesis posits that in an efficient market, successive price changes follow a strict gaussian random variable. In practice, however, a financial asset's price series is said to follow a random walk if successive residual increments are independent and identically distributed (IID). This means that future price changes cannot be predicted from historical price changes. Formally, Campbell et al. (1997) demonstrate that a financial asset's price series (P_t) is said to follow a random walk, if; $P_t = \mu + P_{t-1} + \varepsilon_t$, $\varepsilon_t \sim IDD\ N(0, \partial^2)$, where (P_t) refers to the log of the financial asset's return series under consideration, (i.e., the ASI and individual stock returns) at time (day) *t*; μ is an arbitrary drift parameter; $IID(0, \partial^2)$ means that the residual term (ε_t) is independently and identically distributed with zero mean and unit variance (∂^2). The strict RW hypothesis to be tested is as follows:

H_1 : The ASI and individual stock returns follow a random walk.

On the other hand, a financial asset's price series (P_t) is said to follow a martingale difference sequence (MDS) if it satisfies the following condition: $E[P_{t+1} - P_t \mid P_t, P_{t-1}, \ldots] = 0$, where (P_t) is the log of the economic price series under consideration (i.e., ASI and individual stock returns) at time (day) *t*. This means that a financial asset's expected price change is zero when conditioned on its price history. Thus its price is equally likely to increase, as it is to decrease, which makes predictability impossible. The main difference between the RW and the MDS hypotheses, however, is that the latter relaxes the strict (IID) gaussian random variable assumption to allow for the probable existence of time-varying volatilities in an asset's return series such as conditional hetereoscedasticity, which though expecting successive residual increments to be independent, does not necessarily require it to be identically distributed. The relaxed MDS hypothesis to be tested is as follows:

H_2 : The ASI and individual stock returns follow a martingale difference sequence.

3.4 Research Methodology

The methodology adopted in this study to examine the behaviour of prices on the GSE follows Lo and MacKinlay (1988) and Wright (2000). The basic idea behind the Lo and MacKinlay (1988) hereafter (LM) variance-ratios test is that if a natural logarithm of a time series (p_t) is a pure random walk, then, the variance of its *k*-differences in a finite sample grows linearly with the difference, k. Let (p_t) denote a time series consisting of T observations p_1 , p_2 ,…, p_T of asset returns. Then, the variance-ratio of the *k*-th difference, VR(k), is defined as:

$$VR(k) = \frac{\partial^2(k)}{\partial^2(1)}, \tag{2}$$

where, $VR(k)$ is the variance-ratio of GSE's returns *k*-th differences; $\partial^2(k)$ is the unbiased estimator of $1/k$ of the variance of GSE's returns *k*-th differences, under the null hypothesis; $\partial^2(1)$ is the variance of the first-differenced GSE returns series, and k is the number of days of base observations interval or lag[2], where k = 15, 20, 25 and 30 with regard to this study. The estimated variance, $VR(k)$, values for all k-th lags, under the null hypothesis are expected to be equal to unity if the observed series truly follow a random walk. Now, following LM (1988), the estimator of the k-period difference, $\partial^2(k)$, is calculated as:

$\partial^2(k) = \frac{1}{Tk}\sum_{t=k}^{T}(p_t + ... + p_{t-k+1} - k\hat{\mu})^2$, where $\hat{\mu}$ is the estimated arbitrary drift parameter defined as: $\hat{\mu} = \frac{1}{T}\sum_{t=1}^{T} p_t$, and the unbiased estimator of the variance of the first difference, $\partial^2(1)$, is also computed as follows: $\partial^2(1) = \frac{1}{T}\sum_{t=1}^{T}(p_t - \hat{\mu})^2$. The LM (1988) test statistic is implemented in two specifications. The first test statistic which is construed as testing the strict RW hypothesis with regard to this study, $M_1(k)$ is given by:

$$M_1(k) = \frac{VR(k) - 1}{\phi(k)^{1/2}}, \tag{3}$$

which under the assumption of homoscedasticity, is normally distributed with zero mean, and unit variance, i.e., $N(0,1)$. The homoscedastic-consistent asymptotic variance of the variance ratio, $\phi(k)$, is given by:

$$\phi(k) = \frac{2(2k-1)(k-1)}{3kT}. \tag{4}$$

[2]According to LM (1988: 46), the arbitrary base lag (k) selected, must be any equally spaced integer, which is greater than one. Similarly, the daily base intervals, 15, 20, 25 and 30 have been chosen on that basis.

The hetereoscedasticity-consistent test statistic, which is understood to constitute the relaxed MDS[3] hypothesis with regard to this study, $M_2(k)$, is given by:

$$M_2(k) = \frac{VR(k)-1}{\phi^*(k)^{1/2}}, \tag{5}$$

Unlike the M_1, LM (1988) demonstrate that the M_2 test statistic under the null hypothesis is robust to many forms of hetereoscedasticities and non-normalities. A corresponding hetereoscedasticity-consistent asymptotic variance for the M_2 test statistic is also defined as: $\phi^*(k) = \sum_{j=1}^{k-1}\left[\frac{2(k-j)}{k}\right]^2 \delta(j)$ and $\delta(j) = \frac{\sum_{t=j+1}^{T}(p_t-\hat{\mu})^2(p_{t-j}-\hat{\mu})^2}{\left[\sum_{t=1}^{T}(p_t-\hat{\mu})^2\right]^2}$.

In statistics, non-parametric tests are generally known to be more powerful and better specified (e.g., Lehmann, 1975; Luger, 2003). On this basis, Wright (2000) extends LM's (1988) parametric variance-ratios test to a non-parametric variance-ratios test. The main difference is that Wright's (2000) non-parametric variance-ratios test statistics replace the return differences used in LM (1988) with return ranks and signs. Formally, let $r(p_t)$ be the rank of p_t among $p_1, p_2, \ldots, p_T$. Then, r_{1t} and r_{2t} are the ranks of the returns p_1 and p_2 respectively, defined as:

$$r_{1t} = \left(r\left(p_t - \frac{T+1}{2} \right) \right) \Big/ \sqrt{\frac{(T-1)(T+1)}{12}}, \quad \text{and,}$$

$r_{2t} = \Phi^{-1}(r(p_t)/(T+1))$. According to Wright (2000) the rank series r_{1t} is a simple linear transformation of the ranks, standardized to have zero sample mean and a unit variance. Similarly, the rank series r_{2t} where Φ^{-1} is the inverse of the standard normal cumulative

[3]According to LM (1988), M_2 is a sufficient, but not a necessary condition for the return series to follow MDS.

distribution function, also has zero sample mean and variance approximately equal to one. The rank series r_{1t} and r_{2t} are put in place of p_t in the definition of LM (1988) test statistics, which is written as R_1 and R_2:

$$R_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(r_{1t} + \ldots + r_{1t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{1t}{}^2} - 1 \right) \times \phi(k)^{-1/2}, \tag{6}$$

$$R_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(r_{2t} + \ldots + r_{2t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{2t}{}^2} - 1 \right) \times \phi(k)^{-1/2}, \tag{7}$$

where $\phi(k)$ is defined in (4). Wright (2000) argues that under the assumption that the rank $r(p_t)$ is a random permutation of the numbers $1,2,\ldots,T$, in which each has equal probability, provides the distribution of the test statistics. Therefore, the exact sampling distribution of R_1 and R_2 can be simulated to an arbitrary degree of accuracy, for given choices of T and k. Due to this, the distribution does not suffer from disturbance parameters; hence, it can be used to construct a test with exact power. On the other hand, the test statistic based on the signs, S_1 and S_2 of returns rather than ranks is given by:

$$s_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(s_t + \ldots + s_{t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} s_t{}^2} - 1 \right) \times \phi(k)^{-1/2}, \tag{8}$$

$$s_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(s_t(\overline{\mu}) + \ldots + s_{t-k+1}(\overline{\mu}))^2}{\frac{1}{T}\sum_{t=1}^{T} s_t(\overline{\mu})^2} - 1 \right) \times \phi(k)^{-1/2}, \tag{9}$$

where, $\phi(k)$ is defined in (4), $s_t = 2u(p_t, 0), s_t(\overline{\mu}) = 2u(p_t, \overline{\mu}),$ and

$$u(x_t, q) = \begin{cases} 0.5 & if \quad x_t > q, \\ -0.5 & otherwise. \end{cases}$$

In Monte Carlo experiment and empirical test, Wright (2000) demonstrates that this test can be exact, and more powerful than its traditional alternative under both homoscedastic (RW) and hetereoscedastic (MDS) conditions.

4. EMPIRICAL RESULTS

4.1 Data Properties

Table 2 contains descriptive statistics and diagnostics of computed daily returns for the 20 equities as well as the All Share Index (AS1) over the period under consideration.

Table 2: Summary Descriptive Statistics and Diagnostics of Stock Returns

Stocks	Mean(%)	Std Dev(%)	Skewness	Kurtosis	[1]K-S	[1]A-D	[1]N
Abl	-0.143	0.20	-13.40	418.63	0.40	438.25	1509
Agc	0.002	1.15	2.19	61.69	0.41	397.90	1517
Alw	0.009	3.19	-8.38	187.90	0.44	61.18	1401
Bat	0.079	0.07	-15.09	494.92	0.40	465.27	2138
Cfao	0.015	2.87	1.57	31.03	0.34	395.66	2138
Eic	0.456	0.17	1.27	79.53	0.42	481.23	2138
Fml	0.170	0.11	5.32	89.13	0.36	346.25	2138
Gbl	0.242	0.19	11.90	175.77	0.47	333.82	1026
Gcb	0.171	0.16	12.38	222.43	0.41	346.40	1484
Ggl	0.169	0.10	2.92	35.52	0.39	359.67	2138
Hfc	-0.049	0.01	5.18	57.77	0.44	465.73	1664
Mgl	0.305	3.43	-43.09	1859.45	0.47	705.30	2138
Mlc	0.022	2.76	3.44	58.36	0.40	321.20	1790
Mogl	0.024	2.23	4.24	31.52	0.40	382.62	2138
Paf	0.107	0.40	7.22	58.79	0.39	489.37	1596
Pz	0.030	0.08	-40.40	1708.99	0.45	630.82	2138
Scb	0.108	0.05	0.84	39.87	0.41	458.96	2138
Sg-ssb	0.027	0.03	-31.48	306.24	0.42	449.19	1575
Sppc	0.060	0.02	4.62	69.54	0.41	535.12	2138
Unil	0.013	4.50	-24.44	888.96	0.20	163.68	2138
ASI	0.031	0.42	6.06	459.60	0.42	592.72	2138

[1]Notes: *A-D* and *K-S* represent Anderson-Darling and Kolmogorov-Smirnov goodness-of-fit critical values, which are all statistically significant at 1% and 5% respectively. *N* refers to the number of daily price series observations while appendix 1 provides full definitions of the names and the relevant sectors of all 20 individual stocks analysed.

The table shows that daily long-term mean returns for all 20 companies and the ASI series are significantly different from zero. With the exception of two stocks, Abl and Hfc, all display positive mean returns behaviour. The standard deviation, a measure of a financial asset's return volatility, is generally large for the market.

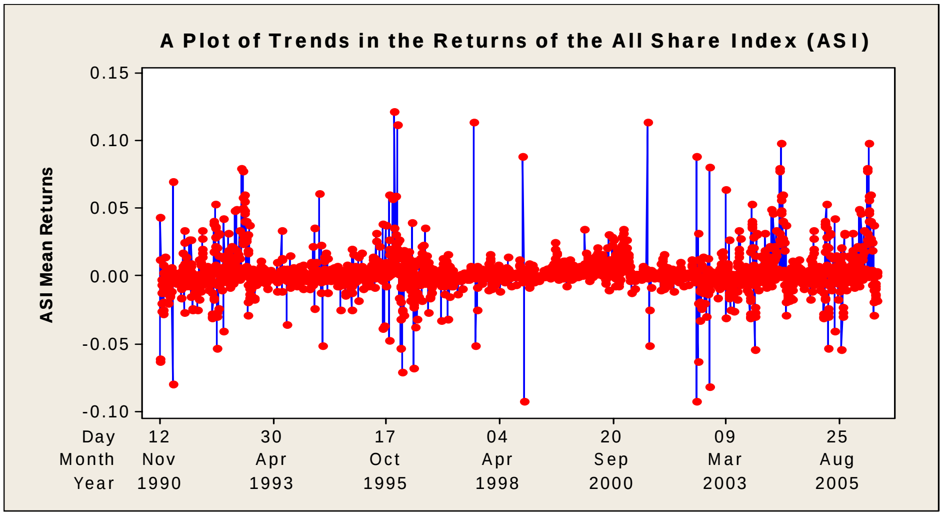

Figure 1: Trends in the Returns of the ASI Series

Figure 1 captures the time series trends in the ASI over the period of interest. It offers further evidence of volatility clustering in the ASI's returns. On the other hand, the null hypothesis of zero skewness for a normal distribution cannot be accepted at any reasonable probability level for all the series investigated. Similarly, the null hypothesis of kurtosis test statistic conforming to that of a normal distribution value of 3 cannot be accepted at any reasonable significance level for any of the analysed series. In addition, Kolmogorov-Smirnov (K-S) and Anderson-Darling (A-D) non-parametric goodness-of-fit tests are applied. While the K-S critical values reject the log-normality assumption for all the series examined including the ASI at the 5% significance level, the A-D test statistic does so at the 1% level. The general evidence of non-normality and volatility clustering in the GSE's return series is not only consistent with the findings of previous studies (e.g., Appiah-Kusi and Menyah 2003), but also conventional theory (e.g., Fama

1965, 1970). Of crucial note is that it justifies the use of non-normality and in particular, hetereoscedasticity-consistent methodology such as Wright's (2000) non-parametric variance-ratios test, if the evidence for or against market efficiency is to be robust.

4.2 The Empirical Results

Table 3 reports the results of the Lo and MacKinlay's (LM) (1988) parametric variance-ratios test statistics over the full sample period for the All Share Index (ASI), and the 11 founding stocks for 15-day, 20-day, 25-day and 30-day base observation intervals. M_1 reports test statistics under the maintained hypothesis of homoscedasticity (RW) whilst M_2 contains critical values under hetereoscedasticity (MDS) hypothesis. The evidence from M_1 suggests that the null hypothesis that the ASI return series follows a random walk is strongly rejected for any of the intervals of k at the 1% significance level. Similarly, the RW is rejected at the 1% level for 8 out of the 11 founding stocks (73%) for any of the intervals of k. By contrast, the RW cannot be rejected at any reasonable significance level for any of the intervals of k for 2 stocks (18%), Mgl and Pz.

Table 3: Lo and MacKinlay (LM) 1988 Parametric Variance-Ratios Test Results

	ASI	Bat	Cfao	Eic	Fml	Ggbl
M_1						
$k=15$	25.401*	4.806*	4.303*	16.268*	25.877*	18.465*
$k=20$	25.659*	4.223*	3.557*	16.521*	28.317*	16.014*
$k=25$	25.182*	3.683*	2.986*	16.477*	30.508*	14.244*
$k=30$	24.083*	3.200*	2.782*	16.115*	32.480*	12.440*
M_2						
$k=15$	6.935*	1.864	0.950	8.115*	4.000*	6.742*
$k=20$	6.421*	1.803	0.727	7.805*	4.965*	4.873*
$k=25$	5.892*	1.686	0.581	7.461*	5.913*	3.740*
$k=30$	5.348*	1.542	0.524	7.065*	6.835*	2.924*

Continuation: Table 3

	Mgl	Mogl	Pz	Scb	Sppc	Unil
M_1						
$k = 15$	-0.276	19.330*	-0.023	8.994*	4.176*	3.151*
$k = 20$	-0.326	19.243*	-0.013	10.000*	5.084*	2.283**
$k = 25$	-0.312	18.273*	-0.012	10.323*	5.581*	1.971**
$k = 30$	-0.288	16.831*	-0.008	10.521*	5.713*	1.900
M_2						
$k = 15$	-1.373	9.835*	-0.061	2.329**	2.492**	2.732*
$k = 20$	-1.271	9.462*	-0.037	2.427**	3.260*	1.979**
$k = 25$	-1.137	8.819*	-0.033	2.395**	3.670*	1.731
$k = 30$	-1.036	8.026*	-0.026	2.361**	3.852*	1.689

Notes: A test statistic with one star indicates significance at 1% level while two stars indicate significance at 5% level.

Generally, the power of the M_1 test statistic decreases as k increases, a revelation which is consistent with that of Lo and MacKinlay (1988). With the exception of Mgl and Pz, all rejections are in the right tail of the null distribution, suggesting the presence of positive autocorrelation in the series. For the remaining 9 stocks in appendix 2, the evidence regarding the RW is rather ambiguous. On the one hand, the RW is rejected for 7 out of the 9 stocks (78%) examined for all lags of k at the 1% significance level. On the other hand, the RW cannot be rejected for 2 stocks (22%), Abl and Sg-ssb at any reasonable probability level for any of the intervals of k.

Results obtained by implementing M_2 indicate that the MDS hypothesis is also rejected for the ASI for all lags of k at the 1% significance level. With regard to the 11 founding stocks analysed, the results of the MDS hypothesis are mixed. Whereas the results of 4 stocks (36%), Eic, Fml, Ggbl and Mogl suggest that the rejection of the RW is robust to hetereoscedasticity, the evidence from another 4 equities (36%), Bat, Cfao, Mogl and Pz shows that the MDS hypothesis cannot be rejected at any acceptable probability level. Again, the power of the M_2 test statistic is inversely related to the lag,

k. The results of the remaining 9 stocks with regard to the MDS hypothesis are even more ambiguous. For 5 stocks (56%), the MDS hypothesis is accepted for all lags of k at any reasonable probability level. Conversely, for another 4 stocks (44%), the MDS hypothesis is rejected at the 1% level for any of the intervals of k.

Due to the ambiguities inherent in the results of the Lo and MacKinlay (1988) variance-ratios test regarding the individual stock returns behaviour in particular, Wright's (2000) version based on ranks and signs are applied to further examine the RW and the MDS hypotheses. Table 4 presents the results of Wright's test for the ASI as well as the 11 founding stocks. R_1 and R_2 report results of the rank based test whilst S_1 and S_2 present the results of the sign based alternative. The R_1 and R_2 test statistics reject the RW for the ASI as well as the 11 stocks for any of the intervals of k at the 1% level of significance. The magnitude of rejections appears to be comparatively stronger than those of the Lo and MacKinlay (1988) test at any of the intervals of k for the entire financial price series investigated.

Table 4: Wright (2000) Non-Parametric Variance-Ratios Test Results

	ASI	Bat	Cfao	Eic	Fml	Ggbl
R_1						
$k=15$	38.615*	32.469*	54.960*	33.673*	136.320*	39.685*
$k=20$	41.048*	34.984*	60.387*	38.118*	155.900*	42.076*
$k=25$	42.300*	36.836*	65.377*	41.592*	172.290*	43.392*
$k=30$	42.691*	38.462*	70.188*	44.671*	186.360*	44.392*
R_2						
$k=15$	36.982*	26.441*	42.038*	26.121*	130.580*	34.274*
$k=20$	38.801*	27.716*	45.337*	29.036*	148.170*	35.387*
$k=25$	39.505*	28.502*	48.501*	31.185*	162.700*	35.789*
$k=30$	39.299*	29.240*	51.700*	33.010*	175.000*	35.773*

Continuation: Table 4

S_1						
$k=15$	141.190*	140.570*	141.190*	148.800*	140.370*	147.490*
$k=20$	163.330*	162.620*	163.330*	171.410*	162.090*	169.940*
$k=25$	182.600*	181.810*	182.600*	190.870*	180.880*	189.410*
$k=30$	199.840*	198.970*	199.840*	208.100*	197.590*	206.750*
S_2						
$k=15$	47.855*	86.810*	105.830*	96.613*	134.340*	71.910*
$k=20$	52.741*	99.003*	121.950*	111.400*	153.550*	80.556*
$k=25$	56.254*	109.570*	136.030*	124.210*	169.850*	87.743*
$k=30$	58.950*	119.130*	148.630*	135.700*	184.170*	93.961*

	Mgl	Mogl	Pz	Scb	Sppc	Unil
R_1						
$k=15$	87.931*	41.184*	50.668*	37.746*	60.607*	38.663*
$k=20$	101.110*	44.950*	57.688*	43.228*	69.408*	41.096*
$k=25$	112.480*	47.367*	63.626*	47.667*	76.785*	42.353*
$k=30$	122.450*	49.012*	68.999*	51.535*	83.050*	42.745*
R_2						
$k=15$	72.121*	37.924*	38.878*	28.182*	46.946*	37.020*
$k=20$	82.547*	40.465*	43.647*	32.067*	53.597*	38.841*
$k=25$	91.536*	41.613*	47.601*	35.060*	59.022*	39.550*
$k=30$	99.326*	42.046*	51.241*	37.620*	63.457*	39.345*
S_1						
$k=15$	140.880*	141.190*	109.860*	83.824*	69.192*	77.374*
$k=20$	162.970*	163.330*	126.500*	96.274*	78.638*	87.033*
$k=25$	182.200*	182.600*	140.900*	107.020*	86.463*	95.001*
$k=30$	199.400*	199.840*	153.800*	116.580*	93.039*	101.82*
S_2						
$k=15$	123.540*	79.301*	107.020*	97.746*	119.470*	47.855*
$k=20$	142.860*	89.916*	123.100*	112.470*	138.030*	52.741*
$k=25$	159.650*	98.430*	137.020*	125.210*	154.070*	56.254*
$k=30$	174.670*	105.660*	149.450*	136.570*	168.300*	58.950*

Note: A test statistic with a star indicates significance at 1% level.

Similarly, S_1 and S_2 test statistics consistently reject the MDS hypothesis for both the ASI, and all 11 founding stocks at the 1% level of significance for all lags of k. By contrast, the power of a test statistic of both the ranks and signs increases with the lag, k, evidence which is also in line with that of Wright (2000). In addition, all rejections are in the upper tail of the null distribution, indicating that the resulting variance ratios are statistically greater than one at all lags for all the analysed series. The results of the remaining 9 individual stocks contained in appendix 3 are similar to those of the ASI, and the 11 founding stocks. The RW and the MDS hypotheses are rejected at all lags for all stocks at the 1% probability level. However, the power of the rank based statistic decreases with the interval k, in contrast to the positive relationship shown by the sign based test statistics. Overall, the magnitude of rejections by the sign based test seems stronger than the rank based alternative, contradictory evidence to that of Wright (2000).

To ascertain the impact of regulatory and market microstructure changes over the period of examination, the test statistics are computed for three[4] sub-sample periods: from 12th November 1990 to 31st December 1997; from 1st January 1998 to 31st December 2002, and from 1st January 2003 to 31st December 2005. For brevity, the sub-sample results of Lo and MacKinlay and Wright tests for the 11 founding stocks are not reported here, but will be available on request. Table 5 presents the sub-sample results of the Lo and MacKinlay test for the ASI. The evidence from M_1 shows that the conclusions based on the full sample are not statistically significantly different from those of the 3 sub-sample periods for the ASI. The RW is consistently rejected for any of the intervals of k at the 1% probability level for the 3 sub-sample periods. It is nevertheless evident that over time, some of the inefficiency seems to have ebbed away. Using the M_2 statistic, the MDS hypothesis similarly cannot be accepted at any reasonable significance

[4]The division of the data has mainly been influenced by two previous studies: Osei's (1998) data ends in 1997 while that of Dewotor and Gborglah (2004) ends in 2002. This is therefore seen as a confirmation as well as an extension of these studies. Note also that the remaining 9 individual stocks did not have enough time series observations to permit similar analysis of sub-sample periods.

level. Unlike M_1, however, the evidence regarding possible reductions in the inefficiency even if statistically insignificant is rather unclear. Statistically, rejection levels for sub-sample period 2 is almost twice compared with those of sub-sample period 1 for any of the intervals of k. And while there are reductions in the rejection levels of sub-sample 3 vis-à-vis sub-sample 2, they are still higher than those of sub-sample 1 for any of the intervals of k.

Table 5: Sub-sample Results of LM's (1988) Variance-Ratios Test for the ASI

	ASI Full Period	ASI[1] Sub-Period 1	ASI[2] Sub-Period 2	ASI[3] Sub-Period 3
M_1				
$k = 15$	25.401*	18.801*	13.520*	7.409*
$k = 20$	25.659*	18.537*	13.545*	8.215*
$k = 25$	25.182*	18.311*	12.732*	8.519*
$k = 30$	24.083*	17.700*	11.719*	8.355*
M_2				
$k = 15$	6.935*	3.710*	6.234*	3.934*
$k = 20$	6.421*	3.328*	5.281*	4.332*
$k = 25$	5.892*	3.060*	4.356*	4.386*
$k = 30$	5.348*	2.800*	3.643*	4.154*

Notes: A test statistic with one star indicates significance at the 1% level. The test statistics under ASI refer to the full sample period (12th November 1990 to 31st December 2005) while that of ASI[1], ASI[2], and ASI[3] are for sub-sample periods (12th November 1990 to 31st December 1997), (1st January 1998 to 31st December 2002), and (1st January 2003 to 31st December 2005) respectively.

The evidence regarding the 11 founding stocks is quite interesting, and statistically different. On average, inefficiency appears to have an inverse relationship with time. In fact, both the M_1 and M_2 test statistics of Bat, Cfao, Mgl, Pz, Scb and Sppc may be described as classic examples of stocks displaying probable regulatory and market microstructure improvements over time. For the Bat stock for example, the RW is rejected for all lags at the 1% level of significance for sub-samples 1 and 2, but the inefficiency gradually disappears over sub-sample 3. The evidence is similar with regard to the MDS hypothesis for the same 6 stocks (55%). And even for the remaining 5 stocks (45%), Eic, Fml, Ggbl, Mogl and Unil in which both the RW and the MDS hypotheses cannot be accepted at any reasonable probability level over the 3 sub-sample periods, there is evidence of significant and consistent reductions in their levels of inefficiencies. Finally, table 6 reports the sub-sample results due to Wright's non-parametric test for the ASI. Similar to the results of the Lo and MacKinlay test, the RW and the MDS hypotheses are rejected for any of the lags of k, both by the ranks and signs based test statistics over the 3 sub-sample periods at the 1% significance level for the ASI.

Table 6: Sub-sample Results of Wright's (2000) Variance-Ratios Test for the ASI

	ASI Full Period	ASI^1 Sub-Period 1	ASI^2 Sub-Period 2	ASI^3 Sub-Period 3
R_1				
$k = 15$	38.615*	28.930*	18.192*	17.491*
$k = 20$	41.048*	31.801*	18.933*	17.763*
$k = 25$	42.300*	33.489*	19.067*	17.688*
$k = 30$	42.691*	34.505*	18.970*	17.140*
R_2				
$k = 15$	36.982*	26.020*	18.167*	17.823*
$k = 20$	38.801*	28.550*	18.255*	18.370*
$k = 25$	39.505*	29.930*	18.122*	18.201*
$k = 30$	39.299*	30.510*	17.792*	17.472*
S_1				
$k = 15$	141.190*	88.392*	82.680*	68.143*
$k = 20$	163.330*	95.162*	101.830*	78.150*
$k = 25$	182.600*	105.840*	113.380*	86.606*
$k = 30$	199.840*	115.240*	123.560*	93.940*
S_2				
$k = 15$	47.855*	32.162*	26.037*	19.725*
$k = 20$	52.741*	36.006*	28.088*	20.938*
$k = 25$	56.254*	38.872*	29.373*	21.593*
$k = 30$	58.950*	41.088*	30.051*	21.869*

Notes: A test statistic with one star indicates significance at 1% level. The test statistics under ASI refer to the full sample period (12th November 1990 to 31st December 2005) while that of ASI^1, ASI^2, and ASI^3 are for sub-sample periods (12^{th} November 1990 to 31^{st} December 1997), (1^{st} January 1998 to 31^{st} December 2002), and (1^{st} January 2003 to 31^{st} December 2005) respectively.

The only difference though is that rejection levels are stronger than those of the Lo and MacKinlay test. Again, there are consistent reductions in the levels of inefficiency over time, but are largely of no statistical relevance. The evidence from the 11 founding stocks, which is available on request, is again not consistent with those of the Lo and MacKinlay test. It fails completely to accept the RW and the MDS hypotheses over the 3 sub-sample periods for the 11 founding stocks at the 1% significance level. And even though there appears to be some successive decreases in the levels of rejections, no stock displays significant tendency towards efficiency as the Lo and MacKinlay's test results purport.

5. CONCLUSION

We have provided empirical re-examination of the weak form efficient markets hypothesis of the Ghana Stock Market. The need for such re-examination has largely been advanced on the back of two overriding themes; that (1) earlier studies suffer from methodological weaknesses, and/or (2) there is the need to capture probable regulatory and market microstructure improvements even if previous studies follow valid methodology. It is instructive to note that the need for empirically robust tests originates from the idea that any rejection or acceptance of the EMH will have limited implications unless it is based on a valid econometric model (e.g., Lo and MacKinlay, 1988).

On this basis, an empirically robust new non-parametric variance-ratios test suggested by Wright (2000) in addition to the Lo and MacKinlay (1988) parametric alternative is applied to re-investigate whether stock returns follow random walk (RW) or martingale difference sequence (MDS) in Ghana. A number of interesting findings emerge from the empirical analysis. Firstly, descriptive statistics and diagnostics of computed returns show that non-normalities are endemic in the market's returns series. On average, returns are found to be characterised by large standard deviations, excess kurtosis, and are either extremely skewed to the right or left, justifying the use of robust methodology. Secondly, in line with prior studies (e.g., Wright, 2000; Belaire-Franch and Opong, 2005a and b), the results of the Lo and MacKinlay (1988) variance-ratios test are generally ambiguous. While it provides conclusive evidence that the All Share Index (ASI) return series violates both the RW and the MDS hypotheses over the full sample period as well as sub-sample periods, results regarding individual stocks are rather mixed. By contrast, the results of the Wright's (2000) test are conclusive. Both the ranks and signs based test statistics consistently reject the RW and the MDS hypotheses over the full sample and sub-sample periods for the return series of the ASI as well as all the 20 individual stocks analysed, at the 1% significance level. Consistent with conventional theory and prior evidence, return series of the ASI is found to display positive serial dependence throughout the entire period of examination while some individual stocks exhibit negative autocorrelation.

The rejection of the weak form efficiency is not only consistent with previous evidence, but also theoretically not surprising. The size of the GSE is comparatively small, and dominated by small capitalization stocks. Associated high average transaction cost, for instance, results in limited market activity and liquidity. Nevertheless, these are only persuasive rather than empirical arguments. It is admitted that evidence from elsewhere (e.g., Appiah-Kusi and Menyah, 2003), has demonstrated, for example, that size alone is neither necessary nor sufficient for a market to be weak form efficient. These theoretical arguments, albeit not sufficient, explain the rejection of the weak form efficiency. The ambiguous evidence from the Lo and MacKinlay (1988) test, raises two important methodological lessons as a guide for future research, that the use of; (1) robust methodology can no longer be considered as a methodological luxury, but rather a necessity, and (2) a single dataset either some market index or a sample of individual stocks alone may not be enough if the evidence for or against efficiency is to be reliable. A major economic implication of this evidence for investors of the GSE is that stock returns are predictable, but whether exploitation will be profitable after transaction costs is unknown. We leave it to future research. The main policy inference from this evidence, however, is that regulatory and market microstructure changes embarked upon so far have not been deep enough to result in significant market efficiency changes.

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7. APPENDICES

Appendix 1: Sectoral Distribution of Sampled Companies of the GSE

A. **Food, Beverage and Tobacco**
1. Accra Brewery Ltd (Abl)
2. British-American Tobacco Ghana Ltd (Bat)
3. Fan Milk Ghana Ltd (Fml)
4. Ghana Brewery Ltd (Gbl)
5. Guinness Ghana Breweries Ltd (Ggbl)

B. **Financial Institutions**
6. Enterprise Insurance Co. (Eic)
7. Ghana Commercial Bank Ltd (Gcb)
8. HFC Bank Ltd (Hfc)
9. SG-SSB Ltd (Sg-ssb)
10. Standard Chartered Bank (Scb)

C. **Manufacturing**
11. Aluworks Ghana Ltd (Alw)
12. Metalloplastica Ghana Ltd (Mgl)
13. Peterson Zochonis Cussons (Pz)
14. Pioneer Aluminium Factory Ltd (Paf)
15. Supper Paper Products Co. (Sppc)

16. Unilever Ghana Ltd (Unil)

D. **Retailing**
17. CFAO Ghana Ltd (Cfao)
18. Mechanical Lloyd Co. (Mlc)
19. Mobil Oil Ghana Ltd (Mogl)

E. **Mining**
20. Ashanti Goldfields Corporation (Agc)

Appendix 2: Lo and MacKinlay (1988) Parametric Variance-Ratios Test Results

	Abl	Agc	Alw	Gbl	Gcb
M_1					
$k = 15$	0.474	6.834*	5.838*	3.971*	3.848*
$k = 20$	0.623	6.620*	5.277*	3.607*	3.836*
$k = 25$	0.572	6.548*	4.791*	3.210*	3.388*
$k = 30$	0.531	6.342*	4.431*	2.210**	2.940**
M_2					
$k = 15$	0.672	1.485	0.873	1.167	2.504**
$k = 20$	0.909	1.423	0.889	1.175	2.632*
$k = 25$	0.837	1.370	0.889	1.115	2.401**
$k = 30$	0.779	1.279	0.889	1.036	2.125**

	Hfc	Mlc	Paf	Sg-ssb
M_1				
$k = 15$	18.752*	7.606*	4.950*	-0.697
$k = 20$	20.336*	7.731*	5.109*	-0.857
$k = 25$	21.235*	7.848*	5.204*	-0.871
$k = 30$	21.680*	7.865*	4.950*	-0.911
M_2				
$k = 15$	5.991*	4.516*	2.144**	-0.439
$k = 20$	6.152*	4.431*	3.230*	-0.556
$k = 25$	6.224*	4.319*	2.265**	-0.594
$k = 30$	6.231*	4.159*	2.172**	-0.650

Notes: A test statistic with one star indicates significance at 1% level while two stars indicate significance at 5% level.

Appendix 3: Wright (2000) Non-Parametric Variance-Ratios Test Results

	Abl	Agc	Alw	Gbl	Gcb
R_1					
$k = 15$	33.089*	34.252*	48.194*	40.811*	44.616*
$k = 20$	36.076*	36.156*	53.547*	46.393*	46.592*
$k = 25$	38.126*	37.585*	57.971*	50.970*	46.907*

$k=30$	39.822*	38.909*	62.050*	55.058*	46.530*

Continuation: Appendix 3

R_2					
$k=15$	27.217*	26.614*	37.804*	30.788*	38.858*
$k=20$	28.969*	27.356*	41.311*	34.684*	40.332*
$k=25$	29.948*	27.847*	44.134*	37.802*	40.310*
$k=30$	30.786*	28.379*	46.817*	40.586*	39.780*
S_1					
$k=15$	126.080*	127.100*	121.690*	104.020*	125.680*
$k=20$	145.750*	146.940*	140.640*	120.070*	145.290*
$k=25$	162.840*	164.170*	157.090*	133.930*	162.320*
$k=30$	178.090*	179.550*	171.760*	146.240*	177.510*
S_2					
$k=15$	77.381*	101.670*	91.954*	89.494*	89.528*
$k=20$	88.619*	117.220*	104.870*	103.230*	102.580*
$k=25$	98.343*	130.820*	115.910*	115.200*	113.580*
$k=30$	106.860*	143.000*	125.600*	125.910*	123.210*

	Hfc	Mlc	Paf	Sg-ssb
R_1				
$k=15$	66.022*	59.901*	74.736*	43.042*
$k=20$	75.355*	67.482*	85.560*	45.760*
$k=25$	83.111*	73.863*	94.855*	46.847*
$k=30$	89.728*	79.438*	102.840*	46.601*
R_2				
$k=15$	58.173*	49.262*	59.708*	41.239*
$k=20$	66.226*	54.978*	68.017*	43.721*
$k=25$	72.751*	59.745*	75.142*	44.631*
$k=30$	78.182*	63.867*	81.139*	44.247*
S_1				
$k=15$	133.230*	138.270*	130.430*	129.220*
$k=20$	154.070*	159.940*	150.820*	149.410*
$k=25$	172.200*	178.790*	168.530*	166.950*
$k=30$	188.390*	195.640*	184.350*	182.620*
S_2				
$k=15$	97.757*	96.024*	107.230*	76.620*
$k=20$	112.420*	110.110*	152.800*	86.626*
$k=25$	124.990*	122.150*	138.210*	95.043*
$k=30$	136.060*	132.810*	150.990*	102.210*

Note: A test statistic with a star indicates significance at 1% level.