

Testing the Random Walk Hypothesis for the Brazilian Stock Market

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ABSTRACT

In this paper the random walk hypothesis is tested for a set of daily/weekly Brazilian stock data given by the São Paulo Stock Exchange Index (IBOVESPA) in the period of 1989-1998. Both the homoscedastic and heteroscedastic versions of Lo-Mackinlay's variance ratio test were used. Our results suggest that prices do not follow a random walk for daily/weekly data for short horizon periods, which would suggest that the Brazilian stock market contains some predictable components. Therefore significant returns to active management could be observed. To test robustness of this result a rolling variance ratio test for different investment horizons was conducted, and it is concluded that prior to 1994 the random walk hypothesis is rejected but after that it cannot be rejected. Institutionally maturing markets, increasing liquidity and the openness of Brazilian markets for international capital can explain the increase of efficiency of the Brazilian stock market.

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1.Introduction

A lot of work has been done by researchers on testing the random walk hypothesis (RWH) for financial price series. Rejection of this hypothesis has serious implications for investors as they can earn profits from forecasting future prices. The rejection of the RWH suggests that stock returns contain predictable components.

Lo and Mackinlay (1988) found that stock returns do not follow random walks for the US markets using a variance ratio test. Poterba and Summers (1988) suggest that the values of variance ratios give evidence of negative autocorrelation (mean reversion) at long investment horizons and positive autocorrelations at short horizons. For an interesting discussion on market efficiency see Fama (1970, 1991).

For international markets, Frennberg and Hansson (1993) used the variance ratio test on the Swedish market and found evidence of positive auto correlated returns for short investment horizons, one to twelve months, and for longer horizons, two years or more, they found indications of negative autocorrelation, in line with research on the U.S. stock market.

Shastri and Shastri (1994) analyze stocks listed in the Tokyo Stock Exchange and found evidence of deviations from the random walk for small-sized stocks using the variance ratio test. They could not reject the RWH for medium sized and larger stocks, though.

Ayadi and Pyun (1994) show that for daily data the RWH could be rejected for the Korean Stock Exchange if the assumption that errors are homoscedastic. However, with heteroscedastic error term, the RWH is rejected.

Grieb and Reyes (1999) used the variance ratio test in order to assess if Latin American Indexes followed a random walk. Using weekly stock returns they found that Brazil indexes

show a greater tendency toward a random walk if compared to Mexico. However, the results for individual firms suggest mean reversion.

Karamera, Ojah and Cole (1999) used the Chow and Denning (1993) multiple variance ratio tests to assess if emerging equity markets were efficient. They found evidence suggesting that the RWH is consistent with the dynamics of returns in most of the emerging markets.

Lee, Gleason and Mathur (2000) examined the French derivatives market to assess whether financial contracts were efficient. They found evidence that the RWH cannot be rejected for these contracts.

The variance ratio test has also been used to assess if foreign exchange rates followed a random walk. Pyun, Ayadi and Chu (1994) examined three major currencies and found evidence rejecting the RWH. For more on this literature the reader is referred to Liu and He (1991), Bahmani-Oskooee (1998), Choi (1999) and the references therein.

These findings suggest that stock market prices and exchange rates may contain predictable components and there may be significant returns to active management. One would like to answer if these patterns are found in emerging markets economies. However, results are mixed.

The purpose of this paper is to contribute to the literature on testing the RWH by examining the Brazilian stock market. This is one of the most important Latin American markets but the literature on this market is almost inexistent.

An important contribution is that the RWH is tested performing rolling variance ratio tests in order to assess if the market has become increasingly more efficient.

The next section describes the data that it is used for testing the RWH and motivates the

use of the Lo-Mackinlay's variance ratio test. Section 3 presents the main ideas behind the variance ratio test. In section 4 results are shown. In section 5 some cointegration and causality tests are done in order to help explain results found in section IV. Section VI concludes the paper.

2. DATA

This paper uses the BOVESPA index to test the RWH for the Brazilian stock market. The BOVESPA index (or IBOVESPA) is the most important indicator of the stock market in Brazil, representing the average behavior of prices of the main stocks at the São Paulo stock exchange. It represents approximately 85% of the total trading in all the stock exchanges in Brazil. The index is the current value of a portfolio starting from a hypothetical investment and it serves as an average indicator of the behavior of the market.

Figure 1

In figure 1 the daily market index from 1986 to 1998 is shown.

Figure 2

In figure 2 the natural log of the IBOVESPA's return is shown.

Fundamental statistics, are given in table 1, and they shed some light on properties of the data for the Brazilian stock market.

Table 1

The nominal returns on the BOVESPA index do not pass the normality test. For the

period in consideration the departure from normality is indicated by the Jarque and Bera (1980) statistic.

A rejection of the RWH for this index would be of much interest. This paper explores if similar patterns as those identified for developed countries apply to the Brazilian stock market.

However, if the rejection is due to heteroscedasticity, which is present in almost all financial time series, then it would be interesting to test consistency of results applying a heteroscedastic-robust statistics.

The Box and Jenkins (1976) methodology tests were implemented to model the returns of the Brazilian stock benchmark index and a “good model” for the IBOVESPA’s return is an ARMA (1,1)-GARCH (1,1) for the 1986-1998 period. The Akaike’s information criteria has been used to choose this model. This motivates the use of the heteroscedastic robust statistics for testing the RWH¹.

Therefore it is used the Lo-MacKinlay’s variance ratio test as it incorporates heteroscedasticity. Using this statistics has become a commonplace in the financial literature, as it is more powerful than the Dickey-Fuller and Box –Pierce tests.

3. The variance ratio test

The variance ratio test was used to check the plausibility of the log of IBOVESPA following a random walk. Let P_t be the log of price, μ a constant drift parameter and ε_t a random disturbance, white noise with normal distribution. Let P_t be a stochastic process satisfying:

¹ See Hamilton (1995).

$$P_t = \mu + P_{t-1} + \varepsilon_t, \text{ with } E[\varepsilon_t] = 0, \text{ for all } t, \quad (3.1.a)$$

or

$$r_t = P_t - P_{t-1} = \mu + \varepsilon_t, \quad (3.1.b)$$

where r_t is the return of one period.

Lo and Mackinlay (1989) exploit the fact that the variance of the increments in a random walk is linear in the sampling interval². If a series follows a random walk the variance of its q-differences would be q times the variance of its first differences. That is

$$\frac{1}{q} \frac{\text{Var}(P_t - P_{t-q})}{\text{Var}(P_t - P_{t-1})} = 1 \quad (3.2)$$

To accept the RWH this ratio should be statistically indistinguishable from one. Let the data consist of $nq+1$ observations, P_0, P_1, \dots, P_{nq} , where both n and q are arbitrary integers greater than one, then the estimators for μ and σ^2 are:

$$\hat{\mu} = \frac{1}{nq} \sum_{k=1}^{nq} [P_k - P_{k-1}] = \frac{1}{nq} [P_{nq} - P_0] \quad (3.3)$$

$$\hat{\sigma}_a^2 = \frac{1}{nq-1} \sum_{k=1}^{nq} (P_k - P_{k-1} - \hat{\mu})^2 \quad (3.4)$$

The estimator $\hat{\sigma}_a^2$ is simply the unbiased sample variance of the first-difference of P_t .

The unbiased estimator of the variance of the qth differences is:

$$\hat{\sigma}_b^2 = \frac{1}{m} \sum_{k=q}^{nq} (P_k - P_{k-q} - q\hat{\mu})^2 \quad (3.5)$$

with

² See also Campbell (1991), Campbell, Lo and MacKinlay (1997), Campbell and Mankiw (1987), Cochrane (1988), Faust (1992), Richardson (1993) and Richardson and Stock (1989).

$$m \equiv q(nq - q + 1) \left(1 - \left(\frac{q}{nq} \right) \right) \quad (3.6)$$

If the process follows a random walk then

$$M(q) = \frac{\hat{\sigma}_b^2(q)}{\hat{\sigma}_a^2} - 1 \quad (3.7)$$

should be close to zero. Then the standard homoscedastic Z_1 statistics is given by:

$$Z_1(q) = \sqrt{nq} M(q) \left(\frac{2(2q-1)(q-1)}{3q} \right)^{-1/2} \quad (3.8)$$

which has an asymptotically standard normal distribution. Let

$$\hat{V}(q) = \sum_{j=1}^{q-1} \left[\frac{2(q-j)}{q} \right]^2 \hat{\delta}(j) \quad (3.9)$$

and

$$\hat{\delta}(j) = \frac{\sum_{k=j+1}^{nq} (P_k - P_{k-1} - \hat{\mu})^2 \cdot (P_{k-j} - P_{k-j-1} - \hat{\mu})^2}{\left[\sum_{k=1}^{nq} (P_k - P_{k-1} - \hat{\mu})^2 \right]^2} \quad (3.10)$$

The heteroscedasticity-consistent standard normal test-statistics $Z_2(q)$ is:

$$Z_2(q) \equiv \sqrt{nq} M(q) \hat{V}^{-1/2}(q) \quad (3.11)$$

which is also asymptotically normal with zero mean and unit variance.

The null hypothesis of a random walk process can be tested by computing the standardized statistics, which are asymptotically standard normal.

4. Results

The Z_1 -statistics for various investment horizons (2, 4, 8, 16, 32, 48 and 64 days) using daily data in a 3051-day time span from 1986 to 1998 were calculated for the BOVESPA index. The results are reported in table 2 and they show that the RWH is rejected for all

investment horizons with 95% of confidence.

The test for the Z_2 -statistics was also conducted. The results reported in table 2 show that the RWH is rejected for all investment horizons with 95% of confidence. This would lead to the conclusion that the Brazilian stock market is inefficient for all investment horizons up to 64 days.

Table 2

To check the robustness of this test a rolling variance ratio test calculating the Z_1 and Z_2 -statistics using a 1024-day time span was computed. It can be seen that for all investment horizons based on the more recent data the RWH cannot be rejected. This is implied by the fact that as markets become institutionally more mature and more liquid, returns approach a random walk. This fact can be seen in figures 3 to 10.

Figures 3-10

Evidence was found indicating that prior to 1994 the RWH should be rejected but after that it may not be reject. The data were split into two sub-periods, one from 1986 to 1994 and the other from 1994 to 1998. In the first sub-sample the RWH is rejected for all investment horizons for both homoscedastic and heteroscedastic statistics at the conventional five percent level of significance as can be seen in table 3.

Table 3

For the second sub-sample the RWH is rejected only with the homoscedastic statistics for a very short horizon of 2 days. However, this rejection is not supported by the heteroscedastic statistics Table 4 shows that when more recent data is used the RWH cannot be rejected for all investment horizons.

Table 4

Additional tests for RWH were performed using weekly nominal returns for the period 1986-1998. Evidence suggests that for short investment horizons the RWH is rejected. With the heteroscedastic version the RWH can only be rejected for 2 and 4 weeks as can be seen in table 5.

Table 5

As can be seen in figure 11 the variance ratios exceed one and this is indicative of positive serial correlation and does not give rise to mean reversion. The long-run mean reversion that previous US studies (Poterba and Summers (1988) and Fama and French (1988)) have found has not been found in the Brazilian case.

Figure 11

5. Foreign inflows and outflows

Access to the capital markets of many countries, particularly emerging markets, has been severely restricted for nonresidents for long periods. The foreign inflow and outflow data for the stock market is used to analyze if it could have an influence on market efficiency in Brazil. Figure 12 shows the daily traded volume in stocks in the BOVESPA index. An explanation for the results found can be that liquidity had a huge increase after 1994. This could be due to an increase in portfolio inflows and outflows.

Figure 12

A test for equality of means is performed for the period of 1990 to 1994 and for the

period of 1994 to 1998. The mean inflow for the first period was US\$ 420.08 million and for the latter period was US\$ 2,530.02 million. As it can be seen in the table below the null of equality of means is rejected with 99 % confidence. The same occurs to outflows, the mean is around US\$ 231.83 million for the first period and US\$ 2,061.68 million for the latter one.

Table 6

In figures 13, 14 and 15 the portfolio inflows, outflows and net outflows are depicted. Inflows and outflows had a huge increase in the last years and this fact could add efficiency to the Brazilian market. One would still want to know whether there are some relationships between the stock market index and this foreign portfolio inflows-outflows.

Figures 13-15

It would be interesting to answer if there are any relationships between the Bovespa index and both inflows and outflow series. However, the series must be stationary in order for statistics to be meaningful. Unit root tests (both the Dickey and Fuller (1979) and Phillips and Perron (1988)) were done on all series and evidence suggesting that the series are not stationary on their levels but are stationary on the first difference (they are integrated of order 1) were found.

Table 7

Based on these results a cointegration test is performed in order to verify if these variables have a long-run relationship³. Using Johansen's (1991,1995) methodology the null of a cointegrating relationship between the nominal level of the BOVESPA index and foreign

³ In order to assess whether the best model would be one with intercept and trend the Akaike information criteria is minimized. A model with intercept and trend is used which has the minimum Akaike of 30.96684 for a 1-lag

portfolio inflows could not be rejected, as can be seen in table 8.

Table 8

In order to test for the robustness of the results shown above an Engle-Granger type cointegration test is made. The IBOVESPA in differences is regressed in its own past values and past differenced inflows, including an intercept and trend. A unit root test is done for the residuals and the cointegration relationship is found (by rejecting the unit root for the residuals).

6. Summary and concluding notes

Under the assumptions of homoscedasticity and heteroscedasticity the RWH was rejected for daily stock prices at the five- percent level of significance for the whole sample. A rolling variance ratio test gives evidence that this inefficiency was particularly more pronounced in the old data, especially prior to 1994. The data has been divided in two sub-samples and evidence that using recent data we cannot reject the RWH was found. Another aspect that's worth noting is that the long-run mean reversion in Brazil that previous US studies have found was not found in the Brazilian case. Variance ratios are significantly greater than unity

This could be explained by institutionally maturing markets, the increase of liquidity and the openness of the Brazilian markets for international investors. It is concluded that inflows and outflows of foreign portfolio capital indeed increased after 1994.

Evidence of cointegration between the BOVESPA Index and inflows of foreign capital was found. This evidence is tested with an Engle-Granger type cointegration test and using Johansen's methodology,

More research on the subject is needed. In future research the importance of the Brazilian ADR's on increasing the efficiency of the Brazilian market will be assessed.

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Table 1
Summary Statistics for daily returns on the Bovespa Index

Time Span	Mean	Standard Deviation	Skewness	Excess Kurtosis	Jarque-Bera	p-value
01/03/86 to 06/12/98	6.00e-05	0,005269	-0,058485	8,298081	3568,926	0,00
01/03/86 to 05/18/94	3,21e-5	0,005994	-0,078875	6,812333	1240,528	0,00
05/18/94 to 06/12/98	0,000128	0,003350	0,346393	12,09637	3483,997	0,00

Table 2
Variance ratio test, daily nominal returns, 1986-1998 (3051 observations)

Investment Horizon, q days	2	4	6	8	16	32	48	64
Z1	7,90*	7,79*	7,42*	6,99*	6,45*	4,74*	3,81*	2,79*
Z2	5,30*	5,31*	5,15*	4,90*	4,67*	3,61*	3,02*	2,28*

* Indicates that ratios are statistically different from one at the five percent level of significance.

Table 3
Variance ratio test, daily nominal returns, 1986-1994 (2046 observations)

Investment Horizon, q days	2	4	6	8	16	32	48	64
Z1	7,05*	7,57*	7,68*	7,48*	6,74*	4,97*	4,01*	3,02*
Z2	5,09*	5,64*	5,78*	5,74*	5,30*	4,09*	3,43*	2,65*

* Indicates that ratios are statistically different from one at the five percent level of significance.

Table 4
Variance ratio test, daily nominal returns, 1994-1998 (1005 observations)

Investment Horizon, q days	2	4	6	8	16	32	48	64
Z1	2,26*	0,33	- 0,84	-1,83	-0,96	-0,41	- 0,32	-0,41
Z2	1,33	0,18	- 0,45	-1,00	-0,56	-0,25	-0,21	- 0,29

* Indicates that ratios are statistically different from one at the five percent level of significance.

Table 5
Variance ratio test, weekly nominal returns, 1986-1998 (650 observations)

Investment Horizon, q days	2	4	6	8	10	12	14	16
Z1	3,96*	3,39*	3,05*	2,58*	2,30*	1,93	1,57	1,18
Z2	2,32*	2,06*	1,94	1,71	1,58	1,37	1,14	0,87

* Indicates that ratios are statistically different from one at the five percent level of significance.

Table 6
Tests for equality of means

Category	t-test	Anova F-Statistic
Inflows	13.74*	188.82*
Outflows	12.10*	146.46*

* Indicates rejection of the hypothesis of equality of means between 1990-1994 and 1994-1998 with 99 % confidence.

Table 7
Unit root tests

	Augmented Dickey- Fuller	Phillips-Perron
BOVESPA	- 0.59	-0.72
1st difference	- 5.44 *	- 9.87 *
INFLOWS	- 1.18	-2.23
1st difference	- 5.97 *	- 16.59 *
OUTFLOWS	-0.39	-1.13
1st difference	- 4.95 *	- 14.01 *

* Indicates rejection of the unit root hypothesis with 95 % confidence.
Allowance for up to fourth-order serial correlation was made and in computing the Phillips-Perron statistic a Newey-West lag window used in order to ensure positive definiteness.

Table 8
Test for cointegrating relationships

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.323632	47.73106	25.32	30.45	None **
0.082674	8.629290	12.25	16.26	At most 1

** denotes rejection of the hypothesis at 1% significance level

L.R. test indicates 1 cointegrating equation(s) at 1% significance level

Unnormalized Cointegrating Coefficients

LOG(IBOVESPA)	LOG(INFLOW)	TREND
-0.385876	0.095658	0.005794
0.200964	0.050875	-0.007046

Normalized Cointegrating Coefficients: 1 Cointegrating Equation(s)

LOG(IBOVESPA)	LOG(INFLOW)	TREND	C
1.000000	-0.247898	-0.015016	-5.668681
	(0.04383)	(0.00288)	

In order to ensure that the tests were not biased or lacked power because of an inappropriate choice of lag length, we considered all lags from 10. The results shown above are for a 1-lag test, which has the minimum multivariate Akaike information criteria.

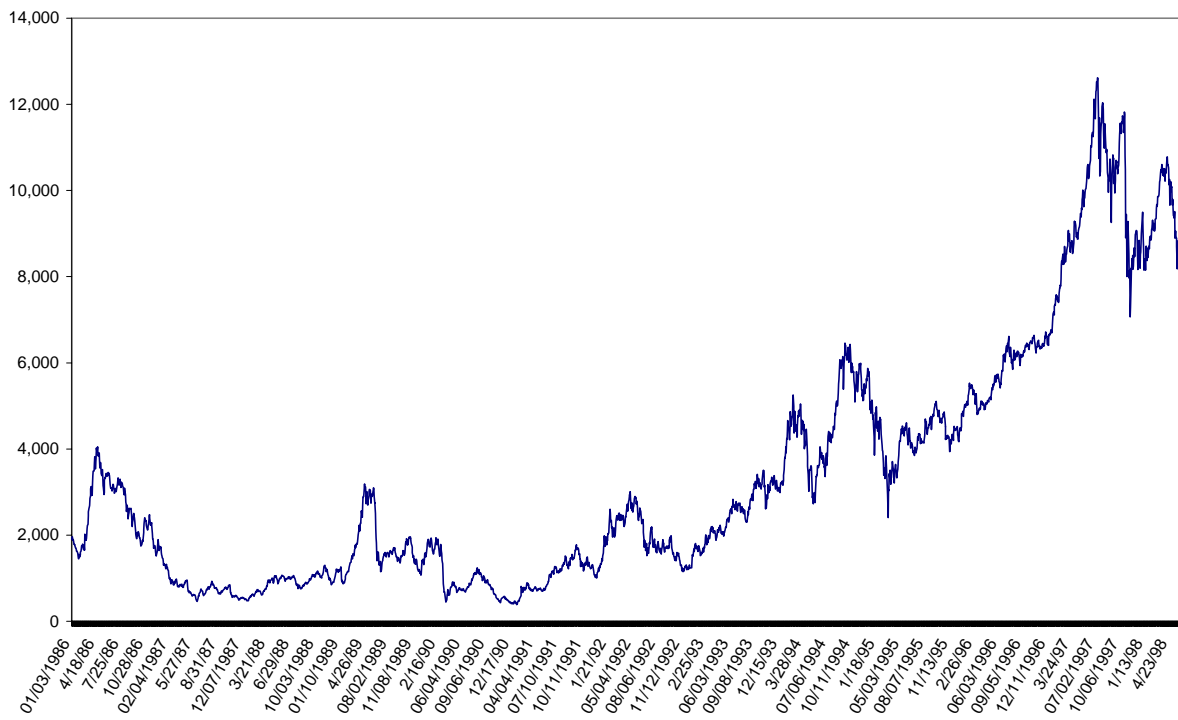


Figure 1. BOVESPA Index

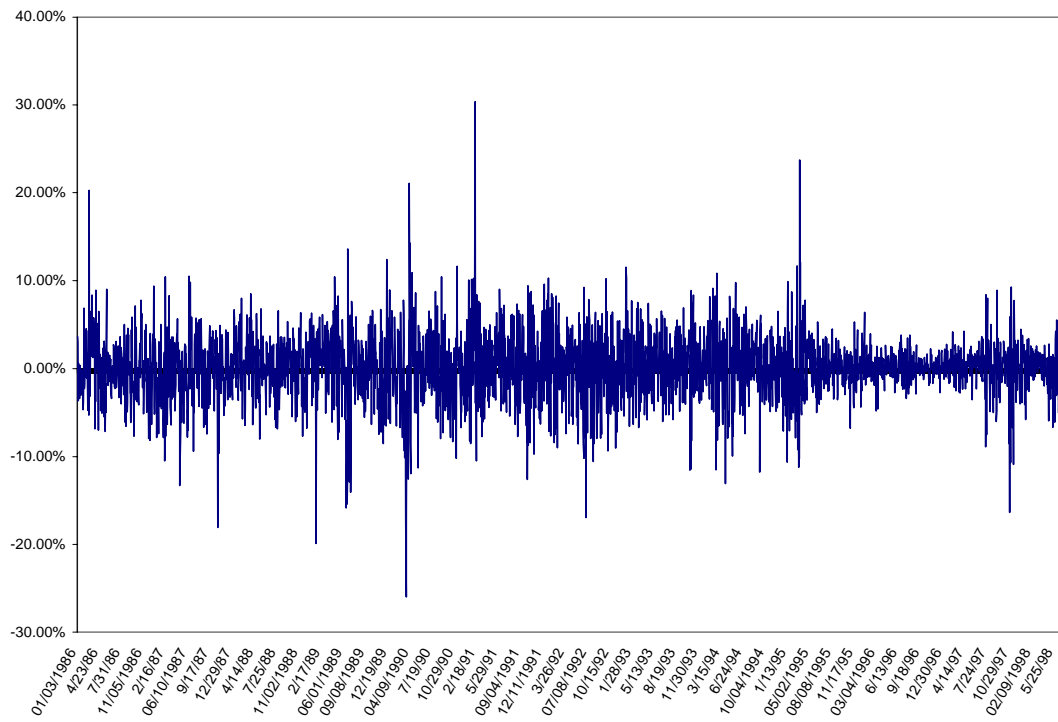


Figure 2. Daily returns for the BOVESPA Index.

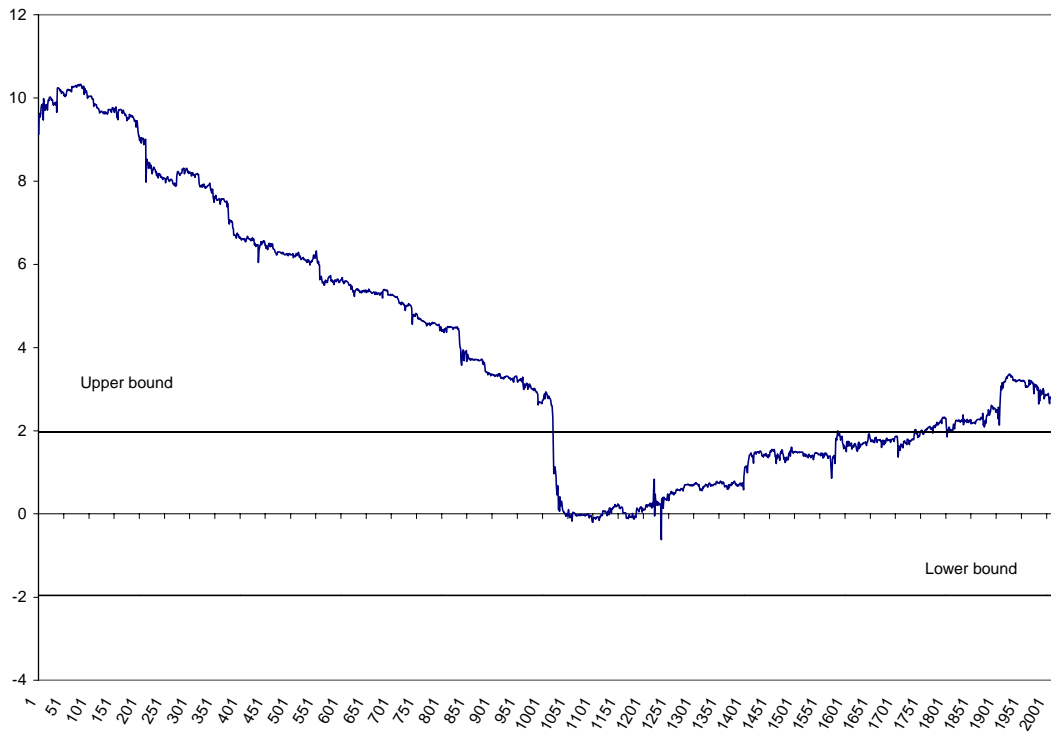


Figure 3. Z1 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 2$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z1 under H_0 .

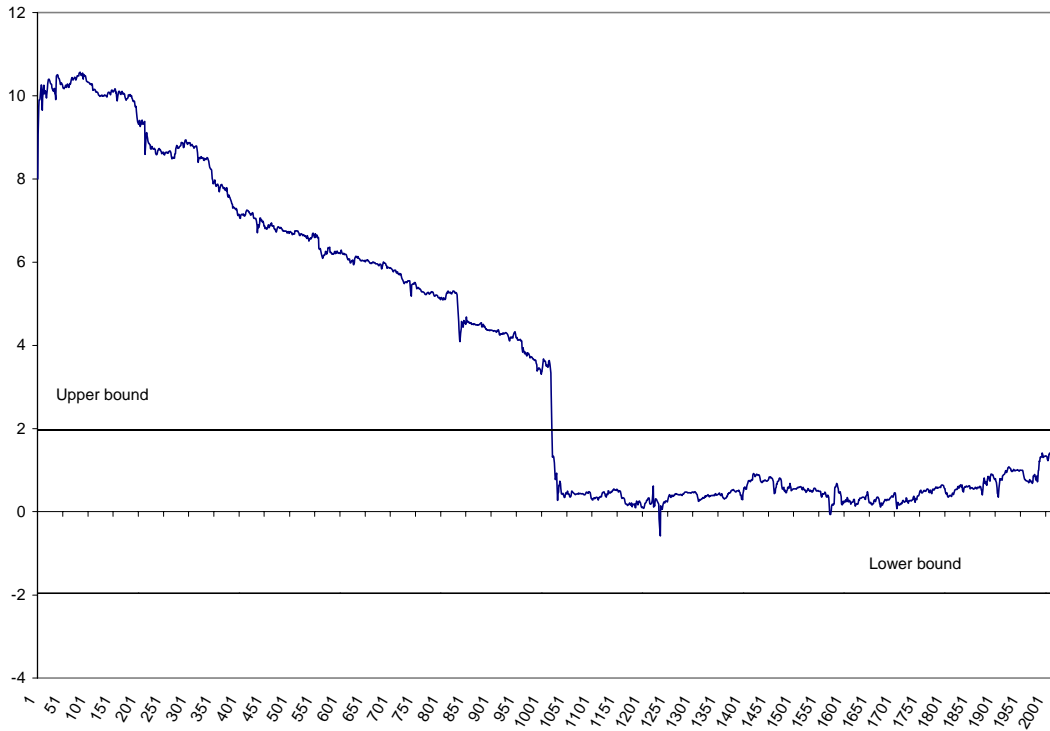


Figure 4. Z1 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 4$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z1 under H_0 .

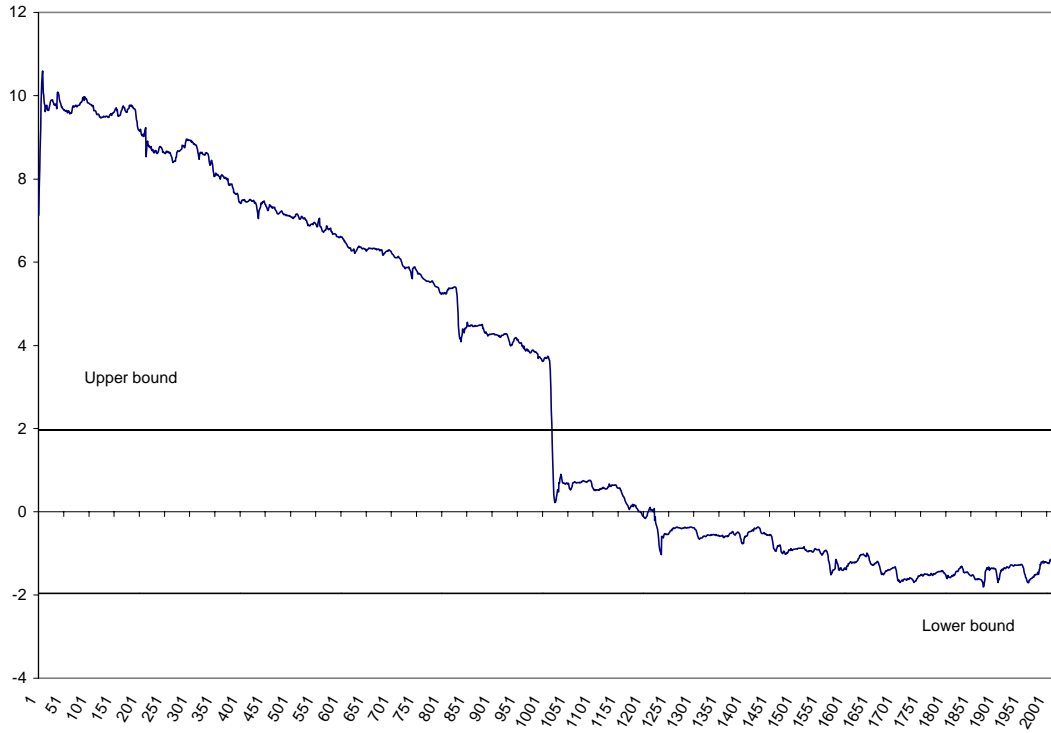


Figure 5. Z1 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 8$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z1 under H_0 .

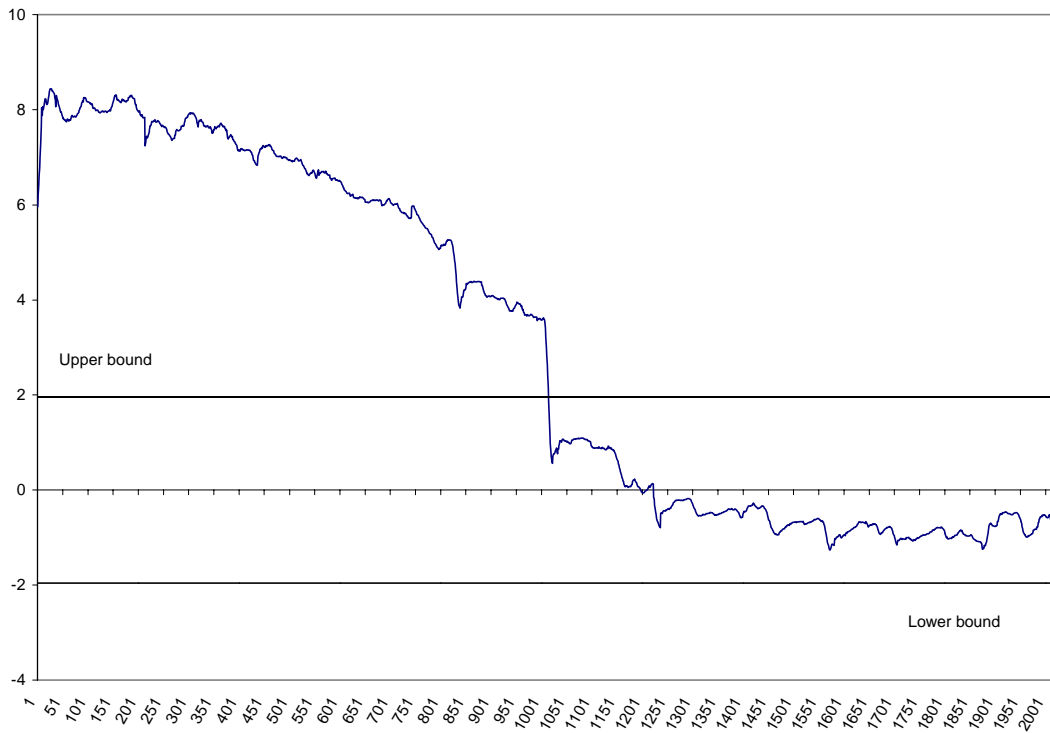


Figure 6. Z1 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 16$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z1 under H_0 .

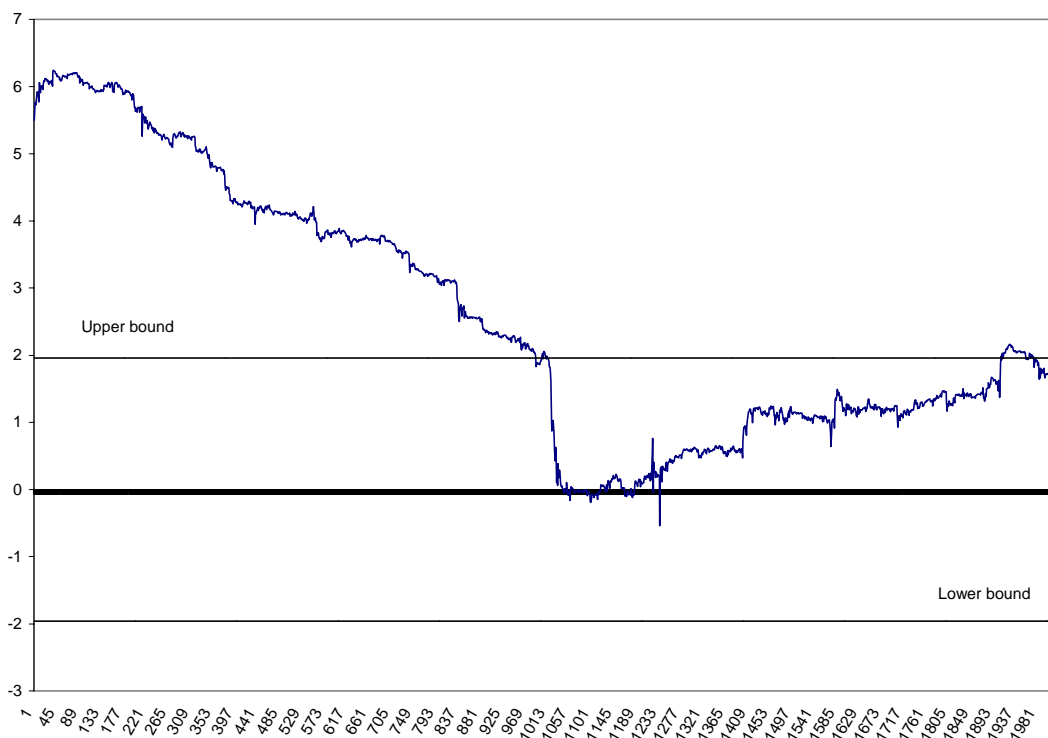


Figure 7. Z_2 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 2$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z_1 under H_0 .

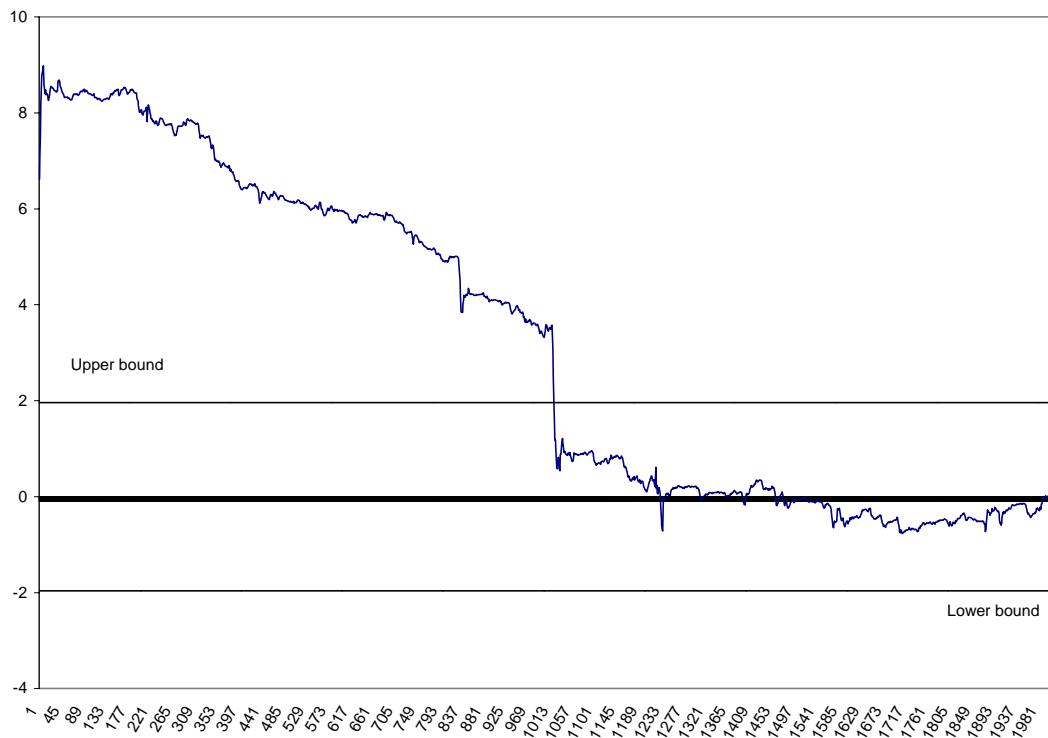


Figure 8. Z_2 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 4$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z_1 under H_0 .

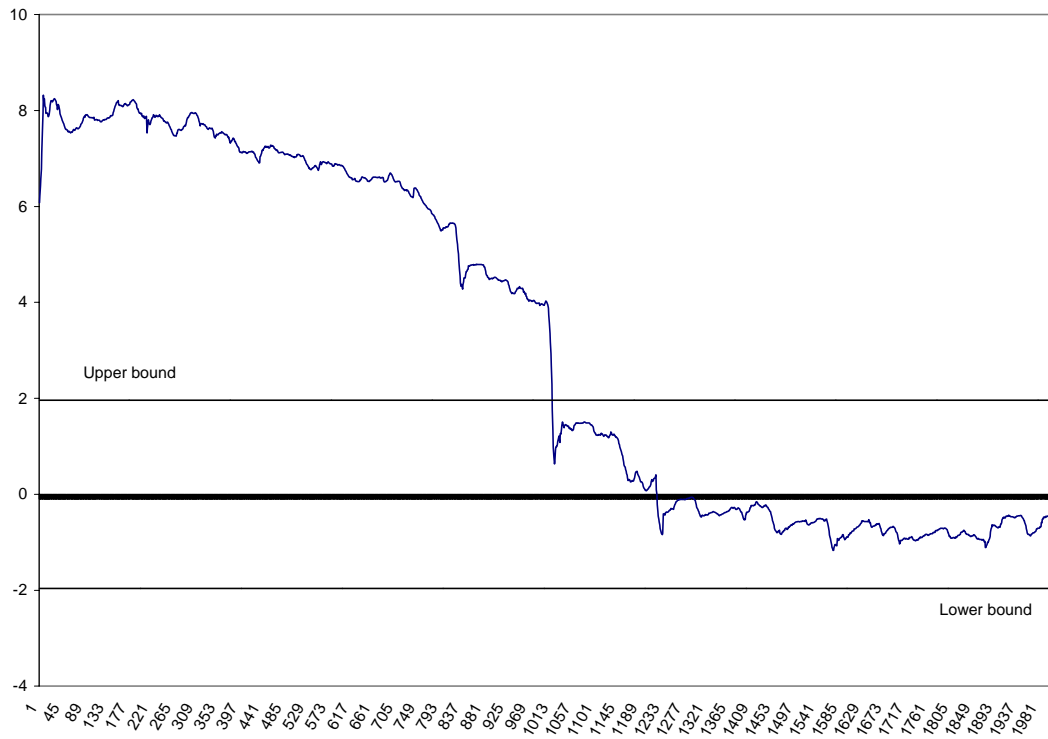


Figure 9. Z_2 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 8$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z_1 under H_0 .

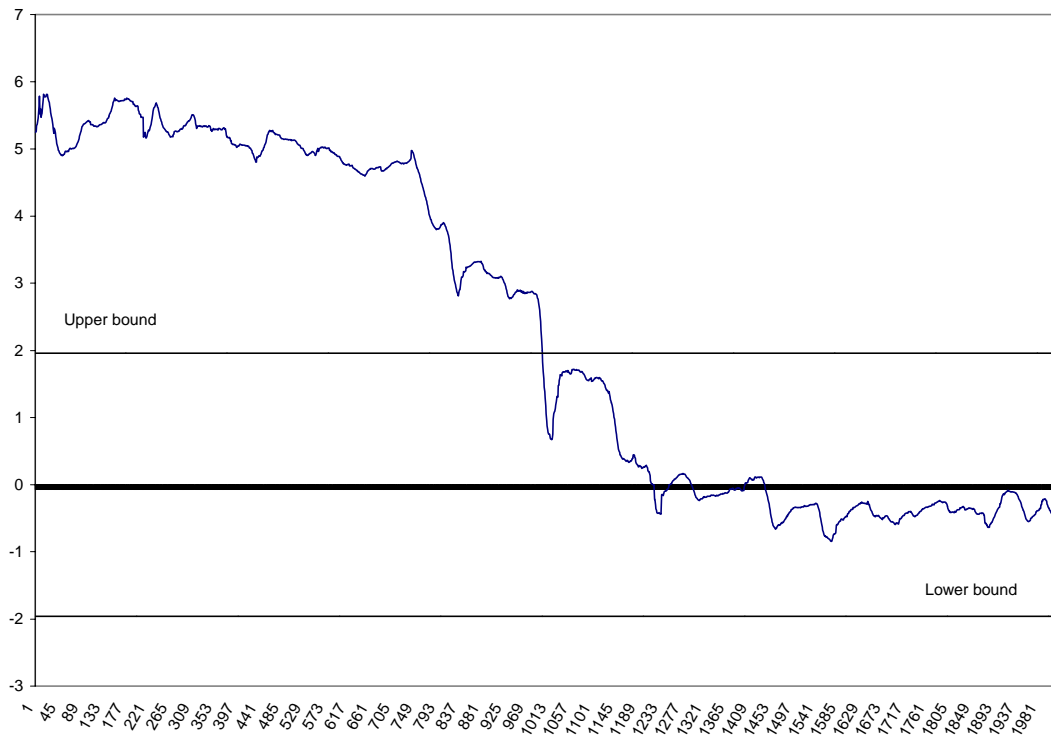


Figure 10. Z_2 estimates for daily nominal returns over a moving 1024 days sample period starting with 01/03/86 and ending with 06/12/98, for an investment horizon $q = 16$ days. Solid lines around 1.96 and -1.96 represent a two-sided 95 % confidence interval for Z_1 under H_0 .

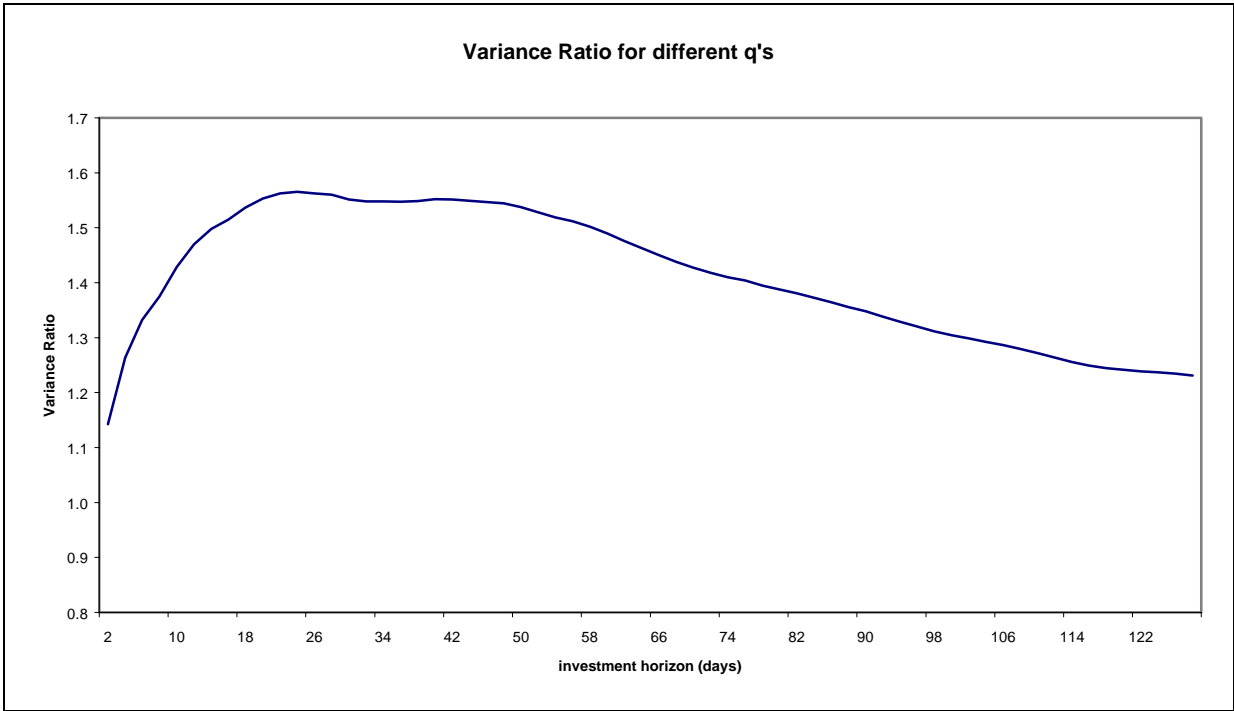


Figure 11. Variance Ratio for different investment horizons.

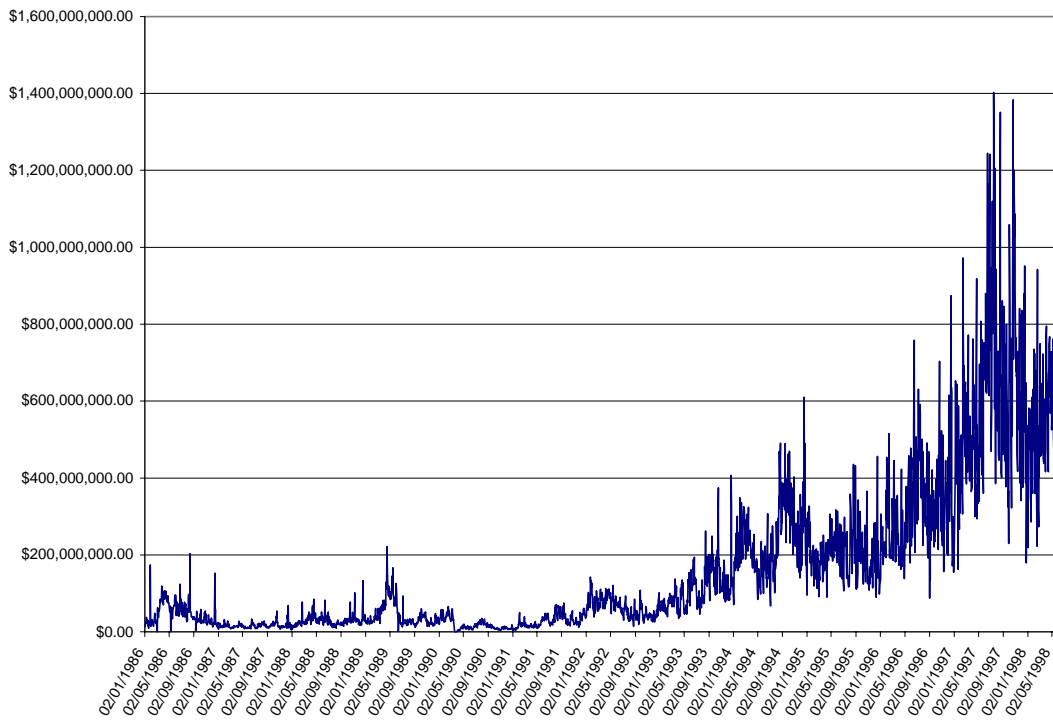


Figure 12. Daily traded volume in stocks in the BOVESPA index starting in 01/03/86 and ending in 06/12/98.

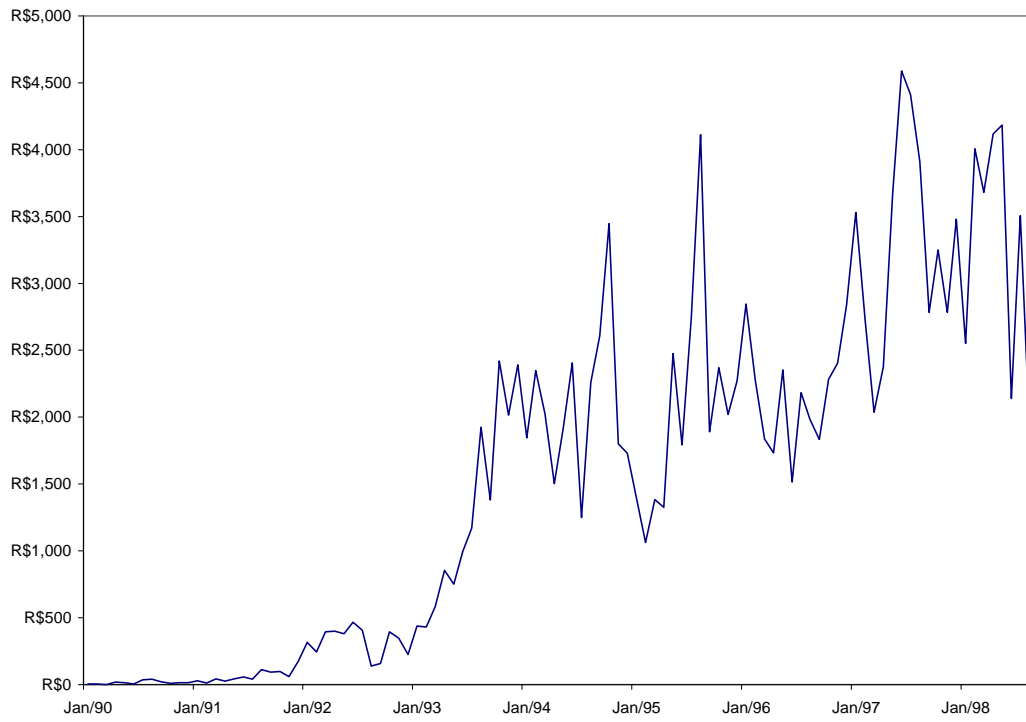


Figure 13. Portfolio Inflows from January 1990 to June 1998.

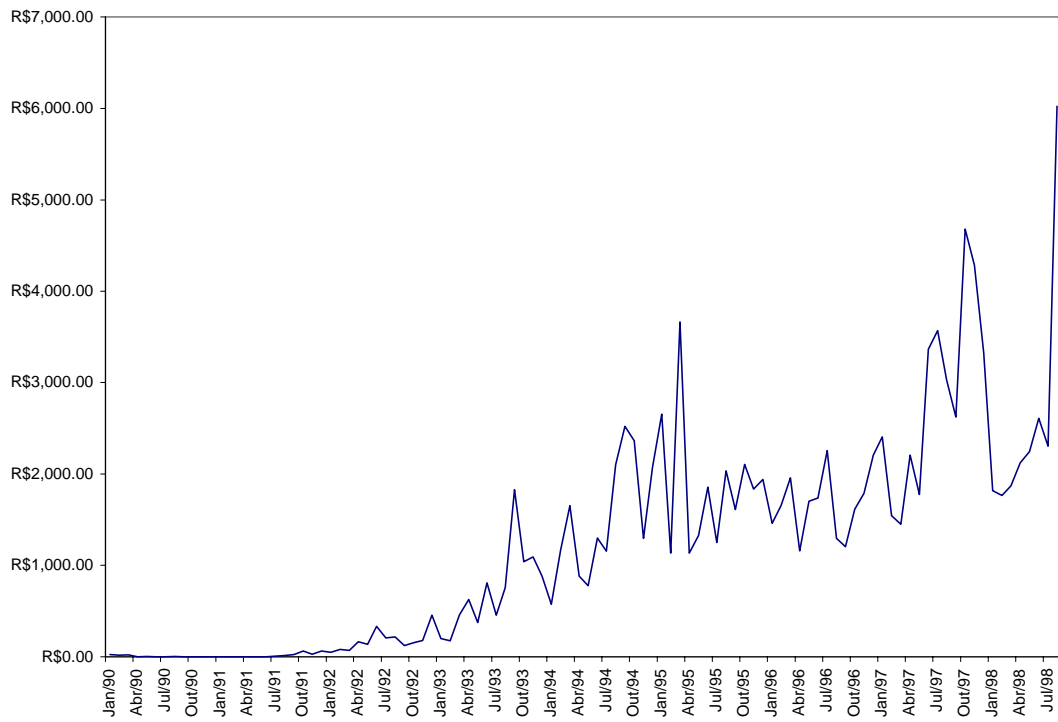


Figure 14. Portfolio Outflows from January 1990 to June 1998.

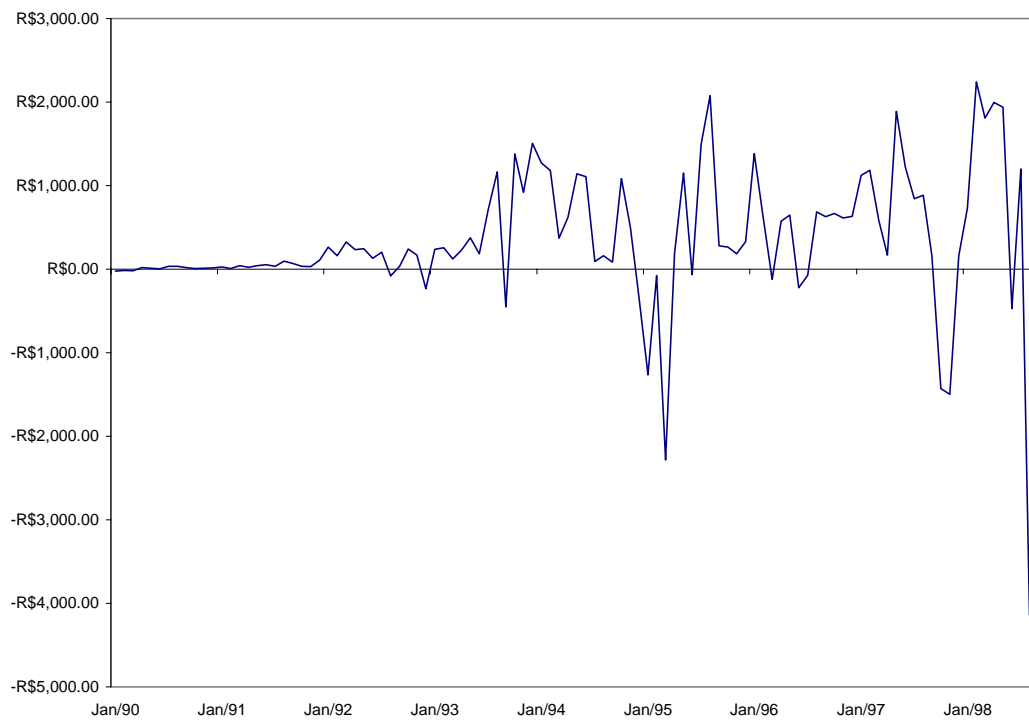


Figure 15. Net Portfolio Outflows from January 1990 to June 1998.