Application of Chow, Cusum and Rolling Window in Testing Stability of Systematic Risk of Companies Listed in WIG-ESG in 2019–2022

Magdalena Mikołajek-Gocejna
SGH Warsaw School of Economics, Institute of Value Management, Poland
mmikol1@sgh.waw.pl
https://orcid.org/0000-0002-8979-2491

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ABSTRACT

The aim of the article is to analyze the stability of beta coefficients of companies listed in WIG-ESG. There are many studies on the stability of companies' systematic risk, but the literature and research lack an analysis of the stability of the beta coefficient for ESG companies.

We examined beta coefficients for 57 companies listed in WIG-ESG, established for sets of daily rates of return between September 3, 2019, to June 6, 2022 (period including COVID-19 crisis and asset price inflation, Russian invasion of Ukraine). We estimate the beta coefficient for the whole as a result of which we obtain the average value of the beta coefficient over the entire analyzed period, and subperiods with fixed length rolling window, resulting in a time series of beta coefficients. To assess beta stability, we used the Chow test with the F statistic, the Cusum test based on generalized fluctuations test framework, and the Wald-Wolfowitz runs test of randomness around the mean for the time series beta coefficients obtained in the rolling window.

The considered tests argue for the instability of the time series of beta coefficients in most of the companies tested: 93% short-term instability cases confirmed by the Chow test, 100% short-term instability cases confirmed by the Wald-Wolfowitz runs test.

The paper is an initial attempt to bridge the gap that presently exists between the theoretical and empirical literature on the stability of ESG companies' systematic risk.

It cannot be ruled out (hypothesis) that the beta coefficient for companies listed in the WIG-ESG index is/will be stable over longer periods of time.

JEL Classification: G11, G12, G13

Keywords: Capital Asset Pricing Model (CAPM), beta coefficient, systematic risk, ESG, environment, social and governance criteria, Cusum Test, Chow Test, rolling window.

1. INTRODUCTION

In recent years, sustainable finance has become one of the most important trends, especially in developed capital markets. Investors, market supervisory authorities and companies, by considering ESG (environmental, social and corporate governance) factors, respond to global challenges that we all face and will face in the coming decades. ESG factors, although they present

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current data, refer primarily to the future, because they show how to effectively manage long-term risk and create value not only for shareholders, but for all stakeholders of the company. The companies that meet the social, environmental, and corporate governance criteria are more aware of the changes taking place in the world, thanks to which they better forecast their future situation, and their operations are more stable and sustainable. In the fifth edition of the GPW survey on the impact of ESG factors on investment decisions, 81% of professional stock market investors in Poland assessed that companies that have implemented the ESG strategy are perceived as entities with lower risk. (GPW, 2019). Moreover, companies with a strong ESG profile are less vulnerable to systematic market shocks and therefore show lower systematic risk (Mikołajek-Gocejna, 2022, pp. 597–615).

Identifying and measuring risk have been of constant interest to both financial theoreticians and practitioners. Various theories have been propounded for pricing of assets considering the risk element. The most common and widely accepted method has been the capital asset pricing model (CAPM) model, which takes into consideration the systematic risk of the asset, measured as the beta coefficient.

The beta coefficient is defined as the ratio of the covariance of the rate of return of the examined financial instrument R_i and the rate of return of the market portfolio R_m to the variance of the rate of return of the market portfolio (Tofallis, 2008, p. 1359):

$$\beta_i = \frac{cov\,(R_i, R_m)}{var(R_m)} = cor(R_i, R_m) \times \sqrt{\frac{var(R_i)}{var(R_m)}}\,, \tag{1}$$

where:
R_i – measures the rate of return of the financial instrument,
R_m – measures the rate of return of the market portfolio,
$cov\,(R_i, R_m)$ is the covariance between the rates of return.

In general, the calculation of the beta coefficient is based on comparing volatility of the rate of return from shares of a specific company in the adopted unit of time with volatility of the rate of return from the stock exchange portfolio (index) adopted for comparison (Dharmaratne, Harris, 2006, pp. 68–61). Since volatility – in this case, of the rate of return – reflects the risk of their realization, the measurement of the beta coefficient means the measurement and comparison of risks related to the investment in the shares of a given entity and the average, previously defined market portfolio, respectively (this measurement should concern the expected rate of return, practice shows however, that beta is calculated on the basis of historical, i.e. realized rate of return).

The beta coefficient is also an estimator of the parameter of simple linear regression equation proposed by Sharpe (1963). Therefore, the rate of return on shares of the *i*-th company in the *t*-th period can be written as (Elton, Gruber, 1998, p. 154; Jajuga, Jajuga, 1998, p. 63):

$$R_{it} = \alpha_i + \beta_{i\,Sharp} R_{mt} + \varepsilon_{it}\,, \tag{2}$$

where:
R_{it} – rate of return of shares of the *i*-th company,
R_{mt} – rate of return on an index of the market,
α_i – the free expression of the model, which is a component of the return on shares of the company and independent of the market situation,
$\beta_{i\,Sharp}$ – the direction coefficient constant over time which measures the expected change in R_i depending on the change in R_m,
ε_{it} – is Gaussian noise N $(0, \sigma_i)$ with zero as expected value and standard deviation σ_i,
t – number of observations of the time series.

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In the Capital Asset Pricing Model, there is an additional variable: risk-free rate of return R_F: (Treynor (1961), Sharpe (1964), Lintner (1965a, 1965b), Mossin (1966))

$$R_i = R_F + \beta_{i\,CAMP}(R_m - R_F) + \varepsilon_i. \quad (3)$$

In the equation, the risk-free return R_F can be a deterministic constant or a random variable.

CAPM is the most frequently and most willingly model of estimation of the cost of capital used in practice, due to its easy implication and interpretation.

The beta coefficient is also called stock aggressiveness. Malkiel and Xu (2006) identified this type of risk as the systematic risk, which is undiversifiable.

Possibilities of using beta in the practice of investment processes are closely related not only to the correctness of its estimation, but also its stability over time (Wright, Mason, and Miles 2003). The Sharpe model and Capital Asset Pricing Model assume that beta is stable and predictable over time. (Treynor, 1965, pp. 63–75).

Thus, the main hypothesis of the article is that beta coefficients of ESG companies listed on the Polish capital market are not stable in short time. Despite the problem of beta stability is quite well described in the literature, results of the stability tests carried out over the years by various researchers are ambiguous, inconclusive, and contradictory. Moreover, literature and research lack an analysis of the stability of the beta coefficient for ESG companies. This paper is an initial attempt to bridge the gap that presently exists between the theoretical and empirical literature on the stability of ESG companies' systematic risk.

2. STABILITY OF ESG COMPANIES BETA – LITERATURE REVIEW

An important issue from the point of view of forecasting and the possibility of making investment decisions on the basis is the analysis of beta stability over time and the study of the sensitivity of its assessments to changes in the method of estimating the model and measurement of variables. Beta instability causes low predictive efficiency of the model, as makes it impossible to use the dependencies described by the model in the future. Moreover, inference based on a model with unstable parameters may result in large errors.

2.1. Systematic risk of ESG companies

Literature and research lack an analysis of the beta coefficient stability for ESG companies. Thus, two groups of publications were analyzed. The first covered research on the risk of ESG companies, the second, stability of beta coefficients. It was necessary to combine the two issues and carry out studies on the stability of the systemic risk for ESG companies.

In the literature, there are not many cases of studies analyzing systematic risk of ESG companies or the relationship between ESG factors and company-specific risk (Sassen, Hinze, and Hardeck, 2016; Mikołajek-Gocejna, 2022). Most studies show, that involvement in social and environmental activities leads to improvement in an organization's image, and its credit ratings, as well as lowering the cost of capital (Gangi et al., 2020; Xue et al., 2020), caused largely by a decrease in risks measured appropriately, e.g., by the standard deviation of rates of return or the beta coefficient.

Boutin-Dufresne and Savaria research (2004) showed that corporate social responsibility activities can help diminish the overall business risk of a company, and even improve its long-term risk-adjusted performance.

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Negative correlation between systematic risk and CSR was also confirmed by Jo and Na (2012). Orlitzky and Benjamin (2001) reviewed 18 American cases of studies on the relationship between corporate social performance (CSP) and risk, indicating that integration of ethical factors in corporate management leads to their lower exposure to financial risk. Similar results were obtained by Boutin-Dufresne and Savaria for Canadian firms (2004). Albuquerque et al. (2019) examined the relationship between CSR and firms' systematic risk using a sample of 28578 annual observations of the United States companies over the period 2003–2015 and found that the level of systematic risk is lower for companies with better CSR performance. Similar results were obtained by Shakil (2021), Rehman et al. (2020) and Zhou et al. (2020).

Analysis conducted by Hassan et al. (2021) showed that companies that follow stricter ESG principles are more resilient to systematic market shocks regardless of their country of origin. The authors analyzed 4624 non-financial firms from Africa, Asia, Europe, Latin America, North America, and Oceania over the period 2002–2018. Moreover, Dunna et al. (2018), concluded that high-scoring ESG stocks have lower volatility and betas than lower scoring ESG stocks.

Research conducted by Bouslah, Kryzanowski, and Mzali (2011) showed that not all ESG aspects affect the systematic risk of companies. Employee relations, environment, human rights and corporate governance negatively affect firm risk, but other dimensions (community, diversity and product) do not significantly impact firm risk. Thus, next to the studies that used aggregated ESG measures, there are studies based on individual ESG measures as explanatory variables. For example, Sharfman and Fernando (2008) confirmed the negative correlation between the cost of equity (beta coefficient) and the quality of environmental management in American companies. Zaman et al. (2021) found that eco-innovative companies are less risky. Xue et al. (2020) claimed that involvement in environmental activities can consequently reduce financial risk. Similar results were obtained by Salama et al. (2011). Moreover, Zaman et al. (2021) found a negative relationship between eco-innovation and stock price crash risk. In turn, research conducted by Chen et al. (2020) showed that there is a negative correlation between the dominant role of institutional investors in the shareholding structure of a company and its risk.

2.2. Stability of systematic risk

The problem of beta stability is quite well described in the literature, however, the results of stability tests carried out over the years by various researchers are ambiguous, inconclusive, and contradictory. Most of the analyses were conducted in developed markets, but there are also studies on the stability of systematic risk for companies listed on developing markets. They include both studies on individual stocks as well as portfolios.

Results of empirical work on beta instability can be divided into three groups: those that confirm that beta is stable over time, those that confirm its instability and those that give ambiguous indications (Table 1).

The existence of stability of beta over different phases of the market was confirmed by analyses conducted by Shamsher et al. (1994), Fabozzi and Francis (1977), Fisher and Kamin (1985) Faff (2001), Das (2008), George and Bainy (2012), Harish and Mallikarjunappa (2019).

Several studies documented that beta is time varying because of the influence of micro-economic and macro-economic factors. The time varying nature of beta at the New York Stock Exchange was first discovered by Blume (1971). Instable betas were also confirmed by researches conducted by Sunder (1980), Bos and Newbold (1984) Russel, Impson and Imre (1994), Braun et al. (1995), Brooks et al. (1998), Faff, Hillier, Hillier (2003), Shah, Moonis, (2003), Irala (2007), Sarma and Sarmah (2008), Attya and Eatz (2011), Simon et al. (2012), Mazowina (2013), Celik (2013), Wijethunga and Dayaratne (2015), Ye (2017), Gupta (2020)

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Contradictory results in beta stability were obtained by: Baesel (1974), Levy (1971), Witkowska (2008), Singh (2008), Ray (2010), Deb and Mistra (2011), Terceño et al. (2011), Dubey (2014), Dębski et al. (2011), Ye (2017), Mikołajek-Gocejna (2021).

One of the most widely used methods to estimate beta as a time series process is the Kalman Filter (Kalman, 1960). It has been applied for the estimation of betas and tests for beta constancy in several studies (e. g. Bos, Newbold, 1984; Fisher, Kamin, 1985; Shah, Moonis, 2003). Kalman filters for beta estimation also presented difficulties, due to their failure to deal with the problem of heteroskedasticity (Fisher, Kamin, 1985).

3. METHODOLOGY AND DATA

3.1. Systematic risk estimation and data

In the study, we will estimate the beta coefficient as an estimator of the parameter of simple linear regression equation proposed by Sharpe (1963).

$$R_{it} = \alpha_i + \beta_{i\,Sharp} R_{mt} + \varepsilon_{it}, \tag{4}$$

where t is the index of the moments of time from the period T from which samples of the analyzed rate of returns for the i-th company are derived.

We examined beta coefficients for 57 companies listed in WIG-ESG, established for the sets of daily rates of return between September 3, 2019, to June 6, 2022 (period including COVID-19 crisis and asset price inflation, Russian invasion of Ukraine). To obtain an up-to-date beta rating, the model should be estimated over a relatively short period of time, while maintaining the estimation sample size requirements. Therefore, our studies prefer daily quotations, however we are aware of the limitations of the approach.[1] According to the theoretical assumptions of the Sharp/CAPM model, the market index should cover the broadest spectrum of investment instruments available to investor. Thus, we choose the rate of return from the WIG Index (market index) as the variable explaining the rates of return of individual ESG companies.

We estimate the beta coefficient for:

1) the whole, as a result of which we obtain the average value of the beta coefficient over the entire analysis period,
2) and subperiods with fixed length rolling windows, resulting in a time series of beta coefficients.

In the study covering the whole period, we used the beta coefficient estimation by the OLS regression of the Sharp equation (4), which ensures that estimators are unbiased (or at least asymptotic, unbiased and consistent when the variable R_m is random):

$$\begin{bmatrix} \alpha_i \\ \beta_{i\,Sharp} \end{bmatrix} = [R_m' R_m]^{-1} R_m' R_i, \tag{5}$$

where:

R_i – (n x 1) vector of daily return on assets i,

R_m – (n x 2) matrix of daily return on a market portfolio proxy with 1 in the first column (for intercept).

[1] The use of daily returns avoids the dilemma of how to estimate them that accompanies longer intervals. In addition, aggregating daily returns to e.g., monthly returns causes a loss of important information. An important argument for the use of high-frequency data is also the possibility of obtaining a relatively long sample for a short period of time (i.e., many observations, which gives relatively low standard errors)

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This method is the simplest computationally, although it is numerically less efficient than the one used of definition (1) and efficient recursive algorithms for calculating moments. Due to the purpose of the research, we prioritize the ease of calculations over their efficiency.

In the rolling regression (Zivot and Wang, 2006, pp. 342–349), period T is divided into sub-periods:

1) containing the same number of 20 observations,
2) which we shift in the time domain by one observation (rolling window) from the beginning to the end of the period T,
3) beta coefficient $\beta_{i\,Sharp}(t)$ estimated for the data from a given subperiod (window) is assigned to the end of t of the subperiod:

$$\begin{bmatrix} \alpha_i(t) \\ \beta_{i\,Sharp}(t) \end{bmatrix} = \left[R_m(t)'\,R_m(t)\right]^{-1} R_m(t)'R_i(t), \tag{6}$$

where:

$R_i(t)$ is an (20 x 1) vector of daily return on assets i in which the first element is $R_{i\,t-19}$ and the last is $R_{i\,t}$,

$R_m(t)$ is an (20 x 1) matrix of daily return on a market portfolio proxy in which the first row is the vector $(1, R_{m\,t-19})$ and the last is $(1, R_{m\,t})$.

As a result of the procedure, we obtain a time series of estimated beta coefficients.

The 20-day length of the time window is dictated by the length of the series (686 days), the daily data frequency that corresponds to the average length of month, and by the desire to obtain a given degree of data smoothing, and the number of regressions required (667 for each of the 57 companies). Assigning the result of the beta parameter estimation to the end of the interval, results in no beta assigned to the initial 19 days period.

In the estimation, we assume that the random regression component ε_i is normally distributed.

3.2. Stability testing

The issue of beta stability can be treated as a problem of invariance of their estimates, and it applies both to its stability over time, as well as to no sensitivity to changes in the method and frequency of measurement of variables and methods of model estimation (Tarczyński et al., 2013, p. 71).

To assess beta stability, we used:

1) Chow test (Chow, 1960), with the F statistic,
2) Cusum test (Ploberger and Kramer, 1992), based on the generalized fluctuations test framework,
3) Wald-Wolfowitz runs test of randomness around the mean for the time series beta coefficients obtained in rolling windows.

In the Chow test period T with daily data is divided into two parts T_1 and T_2 with a shifting time of division from the 20th day from the beginning to the 20th day before the end of period T. Thus, the division point covers all possible dates for dividing the series into two disjoint parts with a minimum number of 20 observations in each part. The test compares OLS residuals estimated (just like (5)) from models estimated separately in T_1 and T_2 subsamples with OLS residuals estimated for the whole series[2]:

[2] Here and further designations in the equation adapted to the designations of the variables in the article.

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$$F_i(t) = \frac{\hat{u}_i^T \hat{u}_i - \hat{e}_i^T(t)\hat{e}_i(t)}{\hat{e}_i^T(t)\hat{e}_i(t) / (n-2k)}, \tag{7}$$

where:

$t = 20 \ldots (n-19)$ is the division point of period T,

$\hat{u}_i$ – OLS residuals from the model, where parameters are fitted for all observations,

$\hat{e}_i(t)$ – OLS residuals from the full model, where coefficients in subsamples $1 \leq T_1 \leq t$ and $t+1 \leq T_2 \leq n$ are estimated separately,

n – number of observations,

k – number of regression coefficients ($k=2$),

$F_i(t)$ – has an asymptotic χ^2 distribution with k degrees of freedom ($F_i(t)/k$ has a F distribution with k and $n-2k$ degrees of freedom).

The Cusum test (Ploberger and Kramer, 1992) is based on the recursive residuals. We estimate a simple OLS model (just like (5)) for sub-periods from the first observation to the end of the sub-period. The end of the sub-period varies from the third observation ($k+1$, where $k=2$) to the one before last one ($n-1$). Based on the obtained estimators for data up to the moment $t-1$, we predict the value of the rate of return R_{it} of the financial instrument for the moment t with an error:

$$\hat{u}_{it} = R_{it} - [\alpha_i(t-1) + \beta_{i\,Sharp}(t-1)R_{mt}], \tag{8}$$

where:

$\alpha_i(t-1)$, $\beta_{i\,Sharp}(t-1)$ – OLS estimate (6) based on all observations up to $t-1$ of assets i,

$t = (1+k) \ldots n$, (for $k=2$, $t=3 \ldots n$)

The variance of predictor is $\sigma^2\left(1 + [1R_{mt}](R_m(t-1)'R_m(t-1))^{-1}\begin{bmatrix}1\\R_{mt}\end{bmatrix}\right)$, where: $R_m(t-1)$ is a $(t-1 \text{ x } 2)$ matrix of monthly return on a market portfolio proxy in which the first row is the vector $(1, R_{m1})$ and the last is $(1, R_{m(t-1)})$, and σ^2 is the variance of disturbance. After scaling the $\hat{u}_{it}$ errors, we get recursive residuals:

$$w_{it} = \frac{\hat{u}_{it}}{\sqrt{\left(1 + [1R_{mt}]R_m(t-1)'R_m(t-1)\right)^{-1}\begin{bmatrix}1\\R_{mt}\end{bmatrix}}}, \tag{9}$$

with the zero expected value and constant variance σ^2 (homoscedasticity)[3].

We cumulatively sum the standardized recursive residuals obtaining:

$$W_{i\tau} = \frac{1}{\tilde{\sigma}\sqrt{\eta}}\sum\nolimits_{t=3}^{2+\tau} w_{it}, \tag{10}$$

where:

$\eta = n-2$ is the number of recursive residuals,

$\tau = 1 \ldots \eta$ is the index of cumulative sums of recursive residuals,

$\tilde{\sigma} = \frac{1}{n-2}\sum\nolimits_{j=3}^{n}(w_{it} - \overline{w_\iota})^2$ is the variance estimate of w_{it}.

[3] OLS residuals are not homoscedastic, even if the variance of the disturbance is constant.

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When the residuals are Gaussian noise, their cumulative sum takes the form of the Standard Brownian Motion (Wiener Process) (Latała, 2011). It allows to establish the limit $\pm b(\tau)$ beyond which fluctuations indicate changes in the parameters of the regression function (instability):

$$b(\tau) = \lambda(1 + 2\tau), \tag{11}$$

where:
λ determines the confidence level.

Stability of beta coefficients obtained by the moving window method can be understood from the statistical point of view as randomness of their deviations from mean value in the period 2019–2022. With beta stability, deviations from the mean are followed by a rapid return to it (white noise). When deviations cluster we are dealing with instability. For example: in the case of a linear upward trend, initially there is a group of negative deviations from the mean, then positive ones. For a polynomial trend (from quadratic upwards) and a sinusoidal trend, negative and positive deviations from the mean occur alternately. For a stochastic trend (random straying, unit root), a group of positive (or negative) and negative (or positive) deviations from the mean (depending on the observed realization of the process) should be expected successively.

The Wald-Wolfowitz runs test of randomness was used to test the randomness of deviations from the mean. The Wald-Wolfowitz runs test is a nonparametric test (distribution-free). There is no need to make restrictive assumptions concerning the specific distribution.

The Wald-Wolfowitz runs test statistic (Z) compares the realized number R of series of positive and negative deviations from the mean in a time-ordered series with the expected number of series at random deviations from the mean $E(R)$:

$$Z = \frac{R - E(R)}{\sqrt{VAR(R)}}, \tag{12}$$

where:

$E(R) = \frac{2n_1 n_2}{n_1 + n_2} + 1,$

$VAR(R) = \frac{2n_1 n_2(2n_1 n_2 - n_1 - n_2)}{(n_1 + n_2)^2 (n_1 + n_2 - 1)} + 1,$

n_1, n_2 – the number of positive and negative deviations from the mean.

The Z statistic has a standardized normal distribution for a large sample ($n_1 > 10$, $n_2 > 10$).

3.3. Stages of research

The research included six stages:

1) a priori selection of the significance level of the tests $\alpha = 0.05$ (probability of the first type error),
2) estimation of the beta coefficient for the data for the entire period from a given company using the linear OLS regressions,
3) regression stability testing (including beta coefficient) using Chow and Cusum tests,
4) estimation of the time series of beta coefficients in subperiods using the rolling window method (OLS),
5) the Wald-Wolfowitz runs test of randomness around the mean for the time series beta coefficients obtained in rolling windows (ad. 4).

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We conducted the research in the *R* statistical program environment using the test implementation:

1) the Chow test in F Statistics (Fstats) and Cusum test in Empirical Fluctuation Processes (efp), from library: Testing, Monitoring, and Dating Structural Changes (Strucchange) (Zeileis et al., 2002),
2) Wald-Wolfowitz Runs Test (runs.test) from library: Testing Randomness in R (Caeiro, Mateus, 2022),

The data set includes daily rates of return on the market index, rates of return on the index of the analyzed asset for given moments of time (panel data) from September 5, 2019, to June 6, 2022 (observations from 686 periods – days). Simple rates of return were used. Data provider: Warsaw Stock Exchange

4. RESULTS AND DISCUSSION

4.1. Beta stability in Chow and Cusum tests

The estimated beta coefficients shows that investments in ESG companies listed on the Polish capital market were on average perceived as less risky (beta < 1 for all 57 companies) than in the diversified market portfolio, even if we consider a COVID-19 period, inflation, and war crisis.

Results of the Chow stability tests are presented in the graphs in Figure 1 (57 panels), Cusum in Figure 2 (57 panels). Values of the F test statistics are presented in Table 2.

In 53 out of 57 companies (Table 2), the value of the F Chow statistic was high and very unlikely (right tail of the distribution), so at the significance level of $\alpha = 0.05$, it is reasonable to reject the null hypothesis (regression stability) in favor of the alternative hypothesis about instability of the parameters of the regression function. For ABS, GTC, Mabion and Forte (FTE) the Chow test did not allow to reject the hypothesis about the stability of the beta coefficient at the significance level of $\alpha = 0.05$. The mean p-value for the companies was 0.153 over a variation range of 0.053 (Mabion) to 0.233 (ABS). The obtained value of the F statistic allows the adoption of the null hypothesis about the stability of the beta coefficient for the companies.

The Cusum test showed different results. Rejection of the null hypothesis of the stability of the regression coefficients at the significance level $\alpha = 0.05$ as a support of the alternative hypothesis of the instability of the coefficients is justified only in the case of GTN (p-value = 0.003) and PKN Orlen (p-value = 0.018). For the rest of companies, the average p-value was 0.507 with a volatility range from 0.054 for Alior Bank to 0.996 for Kernel. For 55 out of 57 companies the obtained value of the F statistic allows the adoption of the null hypothesis about the stability of the beta coefficient.

Only for 4 companies (ABS, GTC, Mabion and Forte) were there no grounds to reject the null hypothesis of stability according to both tests. In the case of 2 companies (GTN and PKN Orlen) both tests require the rejection of the null hypothesis in favor of the alternative hypothesis of instability of beta parameters. For 51 out of 57 companies Chow and Cusum tests showed divergent results. It may indicate a low power of the Cusum test (low probability of rejecting a false null hypothesis) or too short series of data from periods of hypothetical beta stability (before 2020). Thus, we decided to test beta stability using the rolling window regression method.

4.2. Rolling-window regression method and analysis of beta stationarity

Beta time series charts for individual companies estimated by the rolling window regression method and the average beta level are presented in Figure 3 (57 panels) and Table 4.

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For all of the analyzed companies we reject the hypothesis of beta stationarity over time. The p-value was on average $6.76 * 10^{-95}$ with a range from $3.01 * 10^{-141}$ (PKO) to $3.85 * 10^{-93}$ (MAB).

The outstandingly low risk of making an error of the first type is due to the small number of runs in the studied series. The expected value of the number of series with random deviations from the mean is 331 on average. Meanwhile, the observed (actual) number of series is 36 on average, which is an order of magnitude smaller than the expected number with randomness. In other words, beta values return to the mean too rarely and deviate from it for too long. This can indicate the presence of a deterministic trend and/or autocorrelation without a unit root and/or a stochastic trend (unit root).

CONCLUSIONS

Beta coefficients for the rates of return of most of the 57 ESG companies in the years 2019–2022 are not stable in short term.

The following statistical evidence supports instability:

1. 93% (53 companies out of 57) short-term instability cases confirmed by the Chow test.
2. 100% short-term instability cases confirmed by the Wald-Wolfowitz runs test of randomness around the mean, at the significance level $\alpha = 0.05$, the beta coefficient is unstable in the short term of 2019–2022.

The Cusum test showed different results as the only. Rejection of the null hypothesis of the regression coefficients stability at the significance level $\alpha = 0.05$ as a support of the alternative hypothesis of the instability of the coefficients was justified only in two of the analyzed ESG companies.

Of course, it cannot be ruled out (hypothesis) that the beta coefficient for companies listed in the WIG-ESG index is/will be stable over longer periods of time. Narrowing down the study to the years 2019–2022 was because the index itself has been listed since 2019.

The considered tests argue for the instability of the time series of beta coefficients in most of the companies tested.

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Table 1
Beta stability in academic research

Stability of beta	Author	Market	Period of analysis	Number of stocks	Method of testing
Stable beta	Fabozzi and Francis (1977)	NYSE	January 1966 to December 1971	700	Dummy as variable
	Fisher and Kamin (1985)	NYSE	1926–1979	All listed	cross-sectional regression, variance analysis, Kalman Filter
	Faff (2001)	Australian Stock Exchange	1974 to 1995 (monthly return)	24 industry portfolio	Dummy variable, Regression analysis
	Sromon, Das (2008)	Indian Stock Exchange NSE Nifty	February 1999 to September 2007	39 stocks	Time as variable Dummy as variable
	George and Bainy (2012)	Indian Stock Exchange BSE100 Index	1996–2009	169 stocks	Time as variable Dummy as variable
	Harish and Mallikarjunappa (2019)	Indian Stock Exchange S&P BSE Sensex companies	2000–2014	30 stocks	Chow test, multiple breaking point test, CUSUM test
Instable beta	Blume (1971)	NYSE	January 1926 to June 1968	All listed	Regression analysis Analysis of beta correlations
	Sunder (1980)	NYSE	1926–1975	127 stocks	Variance analysis
	Bos, Newbold (1984)				Kalman Filter
	Russell, Impson and Imre (1994)	NYSE	500, 250, 200, 125, and 100 trading days	2,497 stocks	Variance analysis
	Braun et al. (1995)	NYSE	July 1926–December 1990	CRSP NYSE	Rolling windows, GARCH
	Brooks et al. (1998)	Singapore Stock Exchange	1986 to 1993	247 stocks	OLS regression estimates
	Faff, Hillier, Hillier (2003)	UK	1st January, 1969 to 30th April, 1998	32 industry sector portfolios	GARCH model, rolling window
	Shah, Moonis (2003)	India's Bombay Stock Exchange	1st May 1996 to 30th March 2000	50 stocks	GARCH, Kalman Filter
	Irala (2007)	Indian Stock Market BSE	April 1994 to March2006	660 stocks	statistical significance of the CAPM model (t-Student test)
	Sarma and Sarmah (2008)	Indian Stock Market BSE	December 2001 to November2006	5 stocks	Chow test
	Razvan et al. (2009)	Bukarest Stock Exchange	20th January to 20th July 2009	10 stocks	statistical significance of the CAPM model(t-Student test)
Instable beta	Javid & Ahmad (2011)	Pakistan Stock Market Karachi Stock Exchange	1993–2007	50 stocks	Dummy as variable
	Mazowina (2013)	Zimbabwean Stock Market	February 2009 to 31 December 2012	66 stocks	Chow test

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Table 1 – continued

Stability of beta	Author	Market	Period of analysis	Number of stocks	Method of testing
Instable beta	Celik (2013)	Turkish Stock Market	03.01.2005–31.12.2009	Istanbul Stock Exchange (ISE) sector indices and the ISE-30 All Share Index	Rolling windows
	Simon et al. (2012)	Brazilian stock exchange (BM&FBOVESPA)	2002 and 2011	All stocks	Analysis of beta correlations
	Wijethunga A.W.G. Dayaratne D.A. (2015)	Colombo stock exchange	2005–2013	26 stocks	Rolling windows
	Ye (2017)	China's Stock Exchange Shanghai Stock Exchange and the Shenzhen Stock Exchange	Before 2008	208 stocks	Dummy as a variable
	Gupta (2020)	Bombay Stock Exchange	January 2006 to January 2018	11 sectors	Chow Test Dummy Variable
	Levy 1971	NYSE	1962–1970	500 stocks	Correlation analysis
	Baesel (1974)	NYSE	January 1950 to 1967	160 stocks	Chow-test
	Witkowska (2008)	Warsaw Stock Exchange	2000–2006	8 stocks	t-Student test
Contractionary results	Singh (2008)	Bombay Stock Exchange BSE	1991–2002	158 stocks	Regression analysis
	Ray (2010)	Bombay Stock Exchange BSE100	January 1996 to December 2009	100 stocks	Time as variable Dummy as variable Chow test
	Deb and Mistra (2011)	Indian Stock Market BSE	1996 to 2010	158 stocks	Dummy as variable
	Terceño et al. (2011)	Hong Kong Stock Exchange	01.01.2005 and 06.31.2009	All stocks	OLS regression estimates
	Dubey (2014)	National Stock Exchange of India	June 15, 2001 to March 31, 2010 t	25 stocks	OLS regression estimates, wavelet filters
	Dębski et al. (2016)	Warsaw Stock Exchange	2005–2013	134 stocks	Chow test
	Dębski et al. (2017)	Warsaw, Frankfurt and Paris Stock Exchange	2005–2015	37 stocks 28 stocks 36 stocks	t-Student test, Chow test
	Ye (2017)	Shenzhen Stock Exchange which	January 2008 to December 2013	208 stocks	t-Student test dummy variable
	Mikołajek-Gocejna (2021)	emerging markets	2005–2021	25 emerging markets indexes	Chow-test Cusum- test Rolling-window

Source: Own collaboration.

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Table 2
Chow and Cusum Test

Walor	Chow.date	Chow.sup.F	Chow.sup.F.pvalue	Cusum.S	Cusum.S.pvalue
IIB	382	15.08185528	0.019973285	0.647821148	0.327845666
DNP	286	30.52889011	1.08E-05	0.491109827	0.646765335
LTS	368	49.32294455	5.43E-10	0.791890783	0.145420383
MIL	378	113.9468673	0	0.734618166	0.204967266
ING	283	77.83149039	1.11E-16	0.534963667	0.548012718
OPL	359	23.97115944	0.00029592	0.409997695	0.824710486
MBK	402	73.54352641	9.90E-16	0.596196782	0.420722389
PGE	365	46.80376457	2.10E-09	0.861671606	0.092397623
CCC	363	88.51940363	0	0.835298751	0.110174712
ABS	129	9.077899211	0.233223383	0.320920321	0.9488163
KRU	129	28.0469548	3.84E-05	0.763552274	0.172902915
ALR	387	155.275043	0	0.9380663	0.053787773
EAT	287	23.49410408	0.000374523	0.708004418	0.238267184
PLW	360	46.23915774	2.84E-09	0.582102012	0.448527549
KTY	438	53.41596002	5.99E-11	0.378141994	0.882660864
BHW	379	114.6822427	0	0.450062631	0.739790413
JSW	381	48.63765734	7.85E-10	0.654193277	0.317402503
GTC	276	9.238391044	0.220097067	0.472763041	0.688630113
CAR	379	39.67107573	9.29E-08	0.534859982	0.548240886
ATT	378	49.23252259	5.70E-10	0.733330974	0.206492187
EUR	377	40.61439883	5.64E-08	0.461204888	0.714829501
BDX	367	22.50915189	0.000607508	0.467051358	0.701606453
ENG	425	19.91837428	0.002127018	0.36816124	0.898235543
KER	608	128.8762717	0	0.232403379	0.965952905
ENA	377	31.76535268	5.74E-06	0.628207876	0.361415019
TPE	359	31.42702312	6.84E-06	0.602723896	0.408187535
FMF	381	39.34008645	1.11E-07	0.511410835	0.600601617
CMR	544	41.60377911	3.34E-08	0.334056038	0.939119414
LCC	377	50.27374761	3.26E-10	0.420610376	0.803214462
WPL	378	55.69859382	1.74E-11	0.454188632	0.730590552
ECH	357	49.21092465	5.77E-10	0.344339182	0.929026721
GPW	316	36.13063626	5.96E-07	0.357433279	0.913294154

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Table 2 – continued

Walor	Chow.date	Chow.sup.F	Chow.sup.F.pvalue	Cusum.S	Cusum.S.pvalue
PKP	373	62.34990402	4.68E-13	0.68056555	0.276606314
VRG	130	16.25462029	0.011777334	0.626268015	0.364851298
CIE	386	32.05733983	4.94E-06	0.48603112	0.658363247
BFT	292	43.38643443	1.30E-08	0.457931241	0.72219986
MAB	367	12.8237853	0.053278843	0.514295356	0.59409052
AMC	371	51.24419302	1.93E-10	0.797223443	0.140659091
FTE	378	11.14458497	0.106267508	0.551025104	0.51311024
LVC	462	27.41579518	5.29E-05	0.500232976	0.625962749
LWB	463	38.86331504	1.42E-07	0.756345023	0.180500265
BRS	352	17.89436681	0.005531515	0.54891527	0.517641872
STP	289	33.46658137	2.38E-06	0.65642274	0.313802547
PXM	358	44.69984055	6.45E-09	0.584578514	0.443570835
GNB	391	5.76518121	2.89E-11	0.430552857	0.782337045
CIG	373	16.75431427	0.009373255	0.599674445	0.414016321
TRK	368	25.21049507	0.000159893	0.566419866	0.480587001
GTN	396	27.7096287	4.56E-05	1.268167143	0.003028214
PKO	368	193.8597071	0	0.648530667	0.32667157
PZU	373	115.5760748	0	0.673814359	0.286678652
PKN	368	82.93981804	0	1.075136042	0.018119942
CDR	349	33.33283174	2.56E-06	0.362188842	0.90684615
LPP	379	91.49276578	0	0.647212353	0.328855338
SPL	373	103.3113881	0	0.641553246	0.338340222
KGH	368	83.82726214	0	0.659523834	0.308841615
CPS	347	35.68615614	7.52E-07	0.44308895	0.755198423
PGN	377	32.00106162	5.09E-06	0.85915987	0.093981604

Source: own estimation.

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Table 3
Linear trend regression

Company	a	a.se	a.t	a.pvalue	b	b.se	b.t	b.pvalue	betats.se	betats.R2	betats.df	betats.F	DW	pv_of_DW
IIB	–0.10934	0.039239	–2.78645	0.0055	0.000773	0.000102	7.591129	1.08E-13	0.506131	0.079744	665	57.62525	0.135391	3.45E-129
DNP	–0.22538	0.038838	–5.80316	1.01E-08	0.00126	0.000101	12.50971	2.14E-32	0.50096	0.190498	665	156.4929	0.142529	3.21E-128
LTS	–0.53456	0.039991	–13.3672	2.88E-36	0.002805	0.000104	27.04442	3.18E-109	0.515826	0.523776	665	731.4004	0.110361	1.30E-132
MIL	–0.61177	0.063329	–9.66015	9.51E-21	0.003704	0.000164	22.54674	4.72E-84	0.816862	0.433249	665	508.3553	0.080081	8.15E-137
ING	–0.5202	0.036921	–14.0898	1.22E-39	0.002388	9.58E-05	24.93442	2.15E-97	0.476226	0.483184	665	621.7251	0.085091	4.08E-136
OPL	–0.36444	0.024154	–15.0882	1.87E-44	0.001569	6.27E-05	25.03753	5.67E-98	0.311554	0.485245	665	626.8779	0.210043	3.02E-119
MBK	–0.43055	0.059367	–7.25233	1.14E-12	0.002994	0.000154	19.44058	5.34E-67	0.765749	0.362377	665	377.936	0.083031	2.11E-136
PGE	–0.65123	0.053985	–12.0632	1.92E-30	0.003359	0.00014	23.99133	4.11E-92	0.696327	0.463962	665	575.584	0.128772	4.33E-130
CCC	–1.11246	0.064932	–17.1328	8.90E-55	0.004509	0.000168	26.77214	1.07E-107	0.837532	0.518725	665	716.7475	0.069055	2.31E-138
ABS	–0.23277	0.028858	–8.06603	3.39E-15	0.000832	7.49E-05	11.11845	1.86E-26	0.372232	0.156755	665	123.62	0.180573	4.01E-123
KRU	–0.56067	0.047961	–11.6901	7.64E-29	0.002366	0.000124	19.02112	9.65E-65	0.618633	0.352359	665	361.8029	0.179437	2.84E-123
ALR	–0.81117	0.057181	–14.1862	4.24E-40	0.004168	0.000148	28.09997	3.96E-115	0.737552	0.542832	665	789.6083	0.078982	5.72E-137
EAT	–0.44618	0.039715	–11.2346	6.18E-27	0.002164	0.000103	21.00701	1.55E-75	0.512267	0.398894	665	441.2944	0.141319	2.20E-128
PLW	–0.23091	0.043952	–5.25359	2.01E-07	0.001608	0.000114	14.1014	1.07E-39	0.566922	0.23019	665	198.8495	0.140928	1.95E-128
KTY	–0.37574	0.036678	–10.2442	5.75E-23	0.001764	9.51E-05	18.54246	3.49E-62	0.473099	0.340816	665	343.8229	0.124189	1.03E-130
BHW	–0.439	0.038992	–11.2588	4.91E-27	0.00227	0.000101	22.44798	1.67E-83	0.502938	0.431095	665	503.9119	0.081999	1.51E-136
JSW	–0.85591	0.098975	–8.64777	3.92E-17	0.004553	0.000257	17.73435	6.51E-58	1.276644	0.321087	665	314.5073	0.085206	4.24E-136
GTC	–0.11969	0.036165	–3.30943	0.000985	0.000739	9.38E-05	7.879995	1.34E-14	0.466479	0.085401	665	62.09431	0.07637	2.46E-137
CAR	–0.35157	0.041364	–8.49942	1.25E-16	0.001759	0.000107	16.39514	5.47E-51	0.533544	0.287857	665	268.8006	0.127661	3.06E-130
ATT	–0.49452	0.056158	–8.80581	1.12E-17	0.002243	0.000146	15.40004	5.43E-46	0.724366	0.262881	665	237.1612	0.096747	1.71E-134
EUR	–0.12467	0.041921	–2.97386	0.003047	0.001648	0.000109	15.15995	8.30E-45	0.540721	0.256837	665	229.8241	0.117675	1.32E-131
BDX	–0.50655	0.039252	–12.9052	3.66E-34	0.001714	0.000102	16.82985	3.26E-53	0.506293	0.298704	665	283.244	0.120805	3.53E-131
ENG	–0.14249	0.018359	–7.76142	3.18E-14	0.000711	4.76E-05	14.93518	1.05E-43	0.236805	0.251176	665	223.0597	0.173244	4.26E-124
KER	–0.55356	0.047807	–11.579	2.25E-28	0.002423	0.000124	19.53706	1.61E-67	0.616645	0.364668	665	381.6967	0.126997	2.48E-130
ENA	–0.42754	0.048882	–8.74644	1.80E-17	0.002521	0.000127	19.88542	2.08E-69	0.630513	0.372896	665	395.4299	0.109046	8.56E-133
TPE	–0.41522	0.068442	–6.06673	2.19E-09	0.002383	0.000178	13.42528	1.55E-36	0.882804	0.21324	665	180.2382	0.093357	5.78E-135
FMF	–0.29596	0.057144	–5.17916	2.96E-07	0.00258	0.000148	17.40339	3.50E-56	0.737075	0.31293	665	302.8781	0.108318	6.80E-133
CMR	–0.44025	0.038053	–11.5692	2.48E-28	0.001823	9.87E-05	18.47179	8.29E-62	0.490838	0.339102	665	341.2069	0.12469	1.20E-130
LCC	–0.23598	0.046138	–5.11457	4.12E-07	0.001223	0.00012	10.22093	7.08E-23	0.595123	0.135766	665	104.4673	0.081938	1.48E-136

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Table 3 – continued

Company	a	a.se	a.t	a.pvalue	b	b.se	b.t	b.pvalue	betats.se	betats.R2	betats.df	betats.F	DW	pv_of_DW
WPL	–0.57783	0.043125	–13.399	2.05E-36	0.00245	0.000112	21.89962	1.84E-80	0.556254	0.419008	665	479.5935	0.121088	3.86E-131
ECH	–0.23806	0.034685	–6.86346	1.54E-11	0.001299	9.00E-05	14.4402	2.60E-41	0.447389	0.238712	665	208.5193	0.104903	2.30E-133
GPW	–0.35757	0.024844	–14.3925	4.40E-41	0.001215	6.44E-05	18.84996	7.97E-64	0.320456	0.348244	665	355.3211	0.149209	2.56E-127
PKP	–0.38135	0.046959	–8.12093	2.25E-15	0.002668	0.000122	21.90694	1.68E-80	0.60571	0.41917	665	479.9141	0.101601	8.03E-134
VRG	–0.25261	0.032935	–7.67011	6.13E-14	0.001151	8.54E-05	13.46807	9.86E-37	0.424815	0.214309	665	181.3888	0.148726	2.21E-127
CIE	–0.52295	0.046032	–11.3605	1.86E-27	0.002109	0.000119	17.65967	1.60E-57	0.593754	0.31925	665	311.8638	0.115442	6.50E-132
BFT	–0.24151	0.038776	–6.22829	8.36E-10	0.001276	0.000101	12.68881	3.42E-33	0.500155	0.194921	665	161.006	0.121956	5.08E-131
MAB	–1.06978	0.096004	–11.1431	1.47E-26	0.004043	0.000249	16.23379	3.61E-50	1.238328	0.283819	665	263.5359	0.16929	1.27E-124
AMC	–0.47292	0.036745	–12.8702	5.26E-34	0.001827	9.53E-05	19.17004	1.53E-65	0.473962	0.355926	665	367.4904	0.13	6.37E-130
FTE	–0.21564	0.057772	–3.73259	0.000206	0.001419	0.00015	9.466455	4.93E-20	0.745177	0.118754	665	89.61378	0.105587	2.86E-133
LVC	–0.48436	0.042387	–11.427	9.79E-28	0.001795	0.00011	16.32939	1.18E-50	0.546735	0.286212	665	266.649	0.141167	2.10E-128
LWB	–0.61397	0.072098	–8.51577	1.10E-16	0.003455	0.000187	18.47396	8.07E-62	0.929971	0.339155	665	341.2873	0.062795	3.03E-139
BRS	–0.23199	0.026468	–8.76469	1.55E-17	0.00121	6.87E-05	17.62468	2.45E-57	0.341406	0.318389	665	310.6292	0.247096	1.84E-114
STP	–0.40903	0.053849	–7.59578	1.04E-13	0.00272	0.00014	19.47433	3.51E-67	0.694585	0.363179	665	379.2497	0.120484	3.19E-131
PXM	–0.39289	0.063313	–6.20561	9.58E-10	0.002432	0.000164	14.80953	4.28E-43	0.816648	0.248012	665	219.3222	0.090427	2.26E-135
GNB	–1.05458	0.082906	–12.7201	2.48E-33	0.004577	0.000215	21.28337	4.67E-77	1.069378	0.405178	665	452.9817	0.141582	2.39E-128
CIG	–0.27678	0.05756	–4.80856	1.88E-06	0.0014	0.000149	9.376604	1.05E-19	0.742444	0.116773	665	87.92071	0.159514	6.24E-126
TRK	–0.50191	0.051612	–9.72467	5.47E-21	0.00203	0.000134	15.16011	8.29E-45	0.665722	0.256841	665	229.829	0.159826	6.87E-126
GTN	–0.85955	0.057786	–14.8747	2.06E-43	0.003045	0.00015	20.3124	9.88E-72	0.745361	0.382884	665	412.5934	0.153256	8.99E-127
PKO	–0.59322	0.044165	–13.4321	1.44E-36	0.003524	0.000115	30.76182	6.43E-130	0.569665	0.587287	665	946.2896	0.060767	1.57E-139
PZU	–0.64264	0.02658	–24.1776	3.73E-93	0.002849	6.89E-05	41.32759	7.33E-186	0.342844	0.71976	665	1707.97	0.096994	1.85E-134
PKN	–0.54446	0.039955	–13.6268	1.81E-37	0.002964	0.000104	28.5984	6.54E-118	0.515367	0.551545	665	817.8687	0.094282	7.77E-135
CDR	–0.2245	0.051361	–4.37095	1.44E-05	0.001865	0.000133	13.99659	3.35E-39	0.662494	0.227557	665	195.9045	0.123868	9.27E-131
LPP	–0.56185	0.055261	–10.1672	1.14E-22	0.003434	0.000143	23.95832	6.29E-92	0.712791	0.463277	665	574.0013	0.088847	1.36E-135
SPL	–0.60266	0.04691	–12.8471	6.69E-34	0.003295	0.000122	27.08268	1.94E-109	0.605076	0.524481	665	733.4715	0.072525	7.11E-138
KGH	–0.83565	0.05662	–14.7588	7.54E-43	0.003914	0.000147	26.64717	5.35E-107	0.730327	0.516389	665	710.0716	0.065246	6.72E-139
CPS	–0.41877	0.033395	–12.5398	1.57E-32	0.001524	8.66E-05	17.59572	3.47E-57	0.430751	0.317675	665	309.6093	0.101721	8.34E-134
PGN	–0.34212	0.030527	–11.2072	8.01E-27	0.001952	7.92E-05	24.64875	8.57E-96	0.393756	0.477432	665	607.561	0.165295	3.71E-125

Source: Own estimation.

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Table 4
Run tests

Company	R	n1	n2	E(R)	VAR(R)	z-value	p-value
IIB	49	348	319	333.8695652	165.8697866	–22.1188	2.08E-108
DNP	46	296	371	330.2833583	162.3096797	–22.3141	2.70E-110
LTS	27	310	357	332.844078	164.8478198	–23.8209	2.03E-125
MIL	12	312	355	333.113943	165.1164523	–24.9899	7.88E-138
ING	22	322	345	334.1034483	166.103309	–24.2164	1.50E-129
OPL	52	317	350	333.6836582	165.6842834	–21.8837	3.71E-106
MBK	32	301	366	331.3328336	163.3475197	–23.4206	2.64E-121
PGE	30	361	306	332.2323838	164.2397293	–23.5832	5.74E-123
CCC	14	326	341	334.3313343	166.3310017	–24.8378	3.50E-136
ABS	48	368	299	330.9310345	162.9497845	–22.1643	7.60E-109
KRU	54	302	365	331.5247376	163.5376538	–21.7017	1.98E-104
ALR	22	302	365	331.5247376	163.5376538	–24.204	2.02E-129
EAT	40	336	331	334.4812594	166.4808845	–22.8231	2.70E-115
PLW	56	334	333	334.4992504	166.498875	–21.5833	2.58E-103
KTY	23	325	342	334.2833583	166.2830534	–24.1397	9.58E-129
BHW	27	289	378	328.5622189	160.6147823	–23.7949	3.77E-125
JSW	35	331	336	334.4812594	166.4808845	–23.2107	3.55E-119
GTC	56	331	336	334.4812594	166.4808845	–21.5831	2.59E-103
CAR	40	306	361	332.2323838	164.2397293	–22.8029	4.30E-115
ATT	28	309	358	332.7001499	164.7046386	–23.7421	1.32E-124
EUR	48	296	371	330.2833583	162.3096797	–22.1571	8.91E-109
BDX	41	326	341	334.3313343	166.3310017	–22.7443	1.64E-114
ENG	46	359	308	332.5502249	164.5555577	–22.338	1.58E-110
KER	38	231	436	302.9970015	136.4867746	–22.6827	6.63E-114
ENA	25	322	345	334.1034483	166.103309	–23.9836	4.12E-127
TPE	46	341	326	334.3313343	166.3310017	–22.3566	1.04E-110
FMF	36	326	341	334.3313343	166.3310017	–23.132	2.21E-118
CMR	48	290	377	328.826087	160.8740499	–22.1409	1.28E-108
LCC	48	306	361	332.2323838	164.2397293	–22.1786	5.53E-109
WPL	34	322	345	334.1034483	166.103309	–23.2853	6.25E-120
ECH	39	308	359	332.5502249	164.5555577	–22.8837	6.75E-116
GPW	48	375	292	329.3358321	161.3754997	–22.1466	1.13E-108
PKP	34	314	353	333.3598201	165.3613967	–23.2796	7.13E-120

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Table 4 – continued

Company	R	n1	n2	E(R)	VAR(R)	z-value	p-value
VRG	45	341	326	334.3313343	166.3310017	–22.4341	1.83E-111
CIE	37	297	370	330.5052474	162.528833	–23.0224	2.78E-117
BFT	45	358	309	332.7001499	164.7046386	–22.4175	2.66E-111
MAB	68	272	395	323.1589205	155.3516684	–20.4716	3.85E-93
AMC	45	317	350	333.6836582	165.6842834	–22.4275	2.12E-111
FTE	56	366	301	331.3328336	163.3475197	–21.5428	6.19E-103
LVC	51	309	358	332.7001499	164.7046386	–21.95	8.66E-107
LWB	33	254	413	315.5487256	148.0876157	–23.2185	2.96E-119
BRS	38	279	388	325.5937031	157.7124301	–22.9006	4.59E-116
STP	47	300	367	331.1349325	163.1515597	–22.2448	1.27E-109
PXM	15	306	361	332.2323838	164.2397293	–24.7536	2.84E-135
GNB	37	262	405	319.1709145	151.5233633	–22.9231	2.74E-116
CIG	51	350	317	333.6836582	165.6842834	–21.9614	6.74E-107
TRK	34	353	314	333.3598201	165.3613967	–23.2796	7.13E-120
GTN	34	326	341	334.3313343	166.3310017	–23.287	6.00E-120
PKO	8	319	348	333.8695652	165.8697866	–25.3023	3.01E-141
PZU	10	305	362	332.0644678	164.072999	–25.1434	1.67E-139
PKN	14	315	352	333.4737631	165.4749691	–24.8353	3.73E-136
CDR	36	324	343	334.2293853	166.2291199	–23.1311	2.25E-118
LPP	10	297	370	330.5052474	162.528833	–25.1403	1.81E-139
SPL	16	330	337	334.4632684	166.462895	–24.6832	1.62E-134
KGH	8	301	366	331.3328336	163.3475197	–25.2984	3.32E-141
CPS	40	329	338	334.4392804	166.4389105	–22.8228	2.72E-115
PGN	34	312	355	333.113943	165.1164523	–23.2778	7.45E-120
Mean	36.07018	316.9123	350.0877	331.3998527	163.4544162	–23.1002	6.76E-95
Min	8	231	292	302.9970015	136.4867746	–25.3023	3E-141
Max	68	375	436	334.4992504	166.498875	–20.4716	3.85E-93

Source: Own estimation

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Figure 1
Chow test

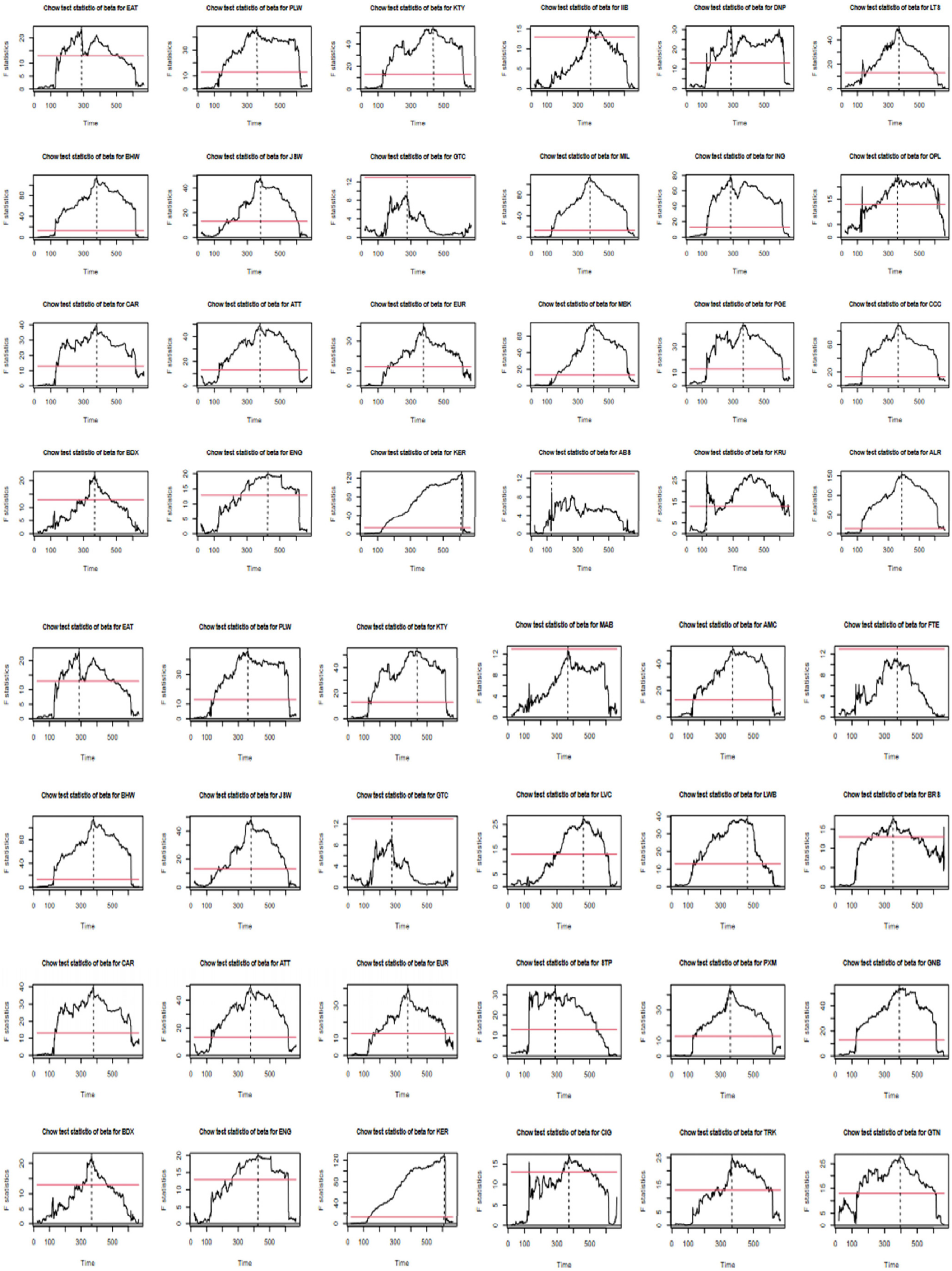

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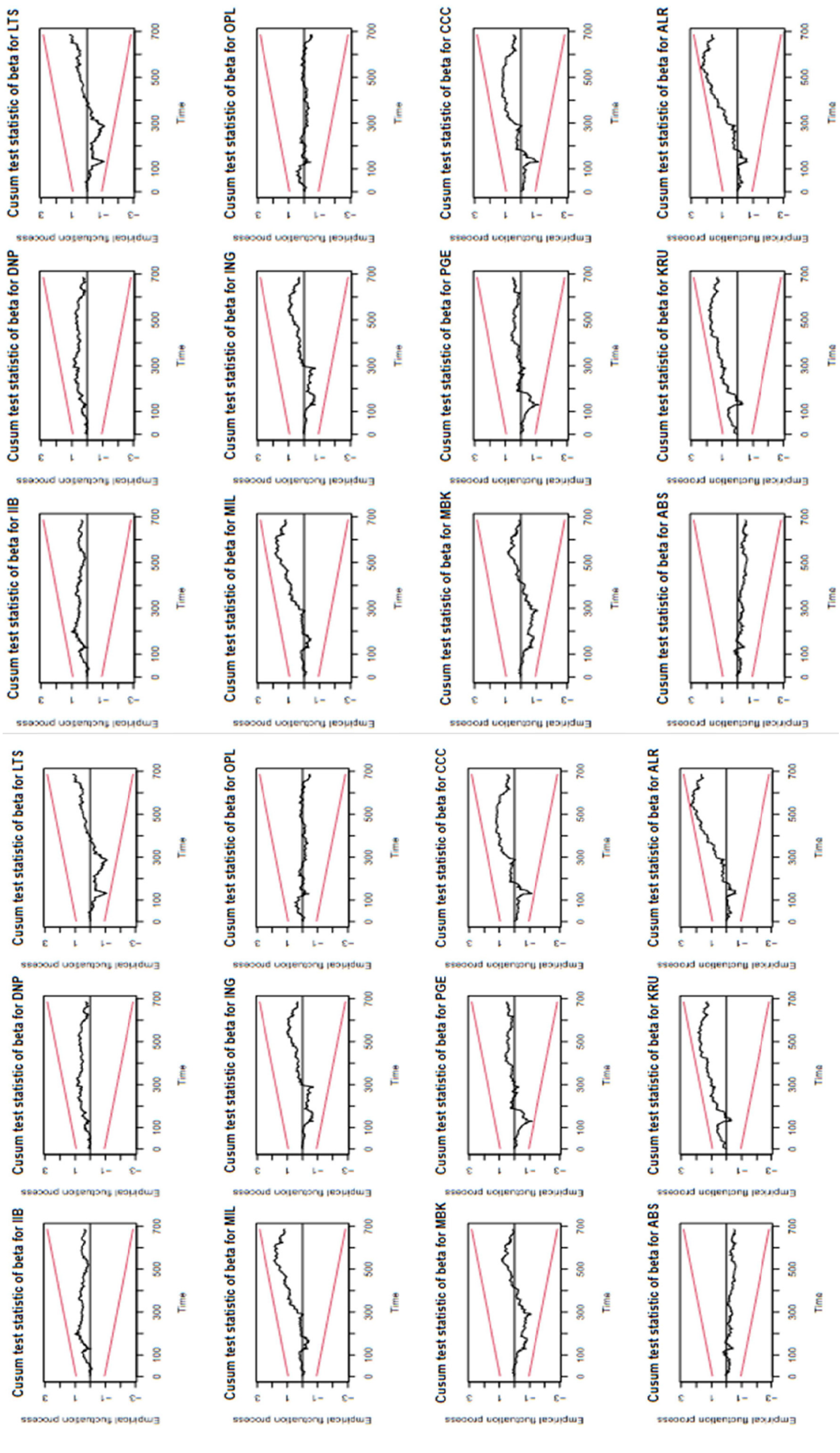
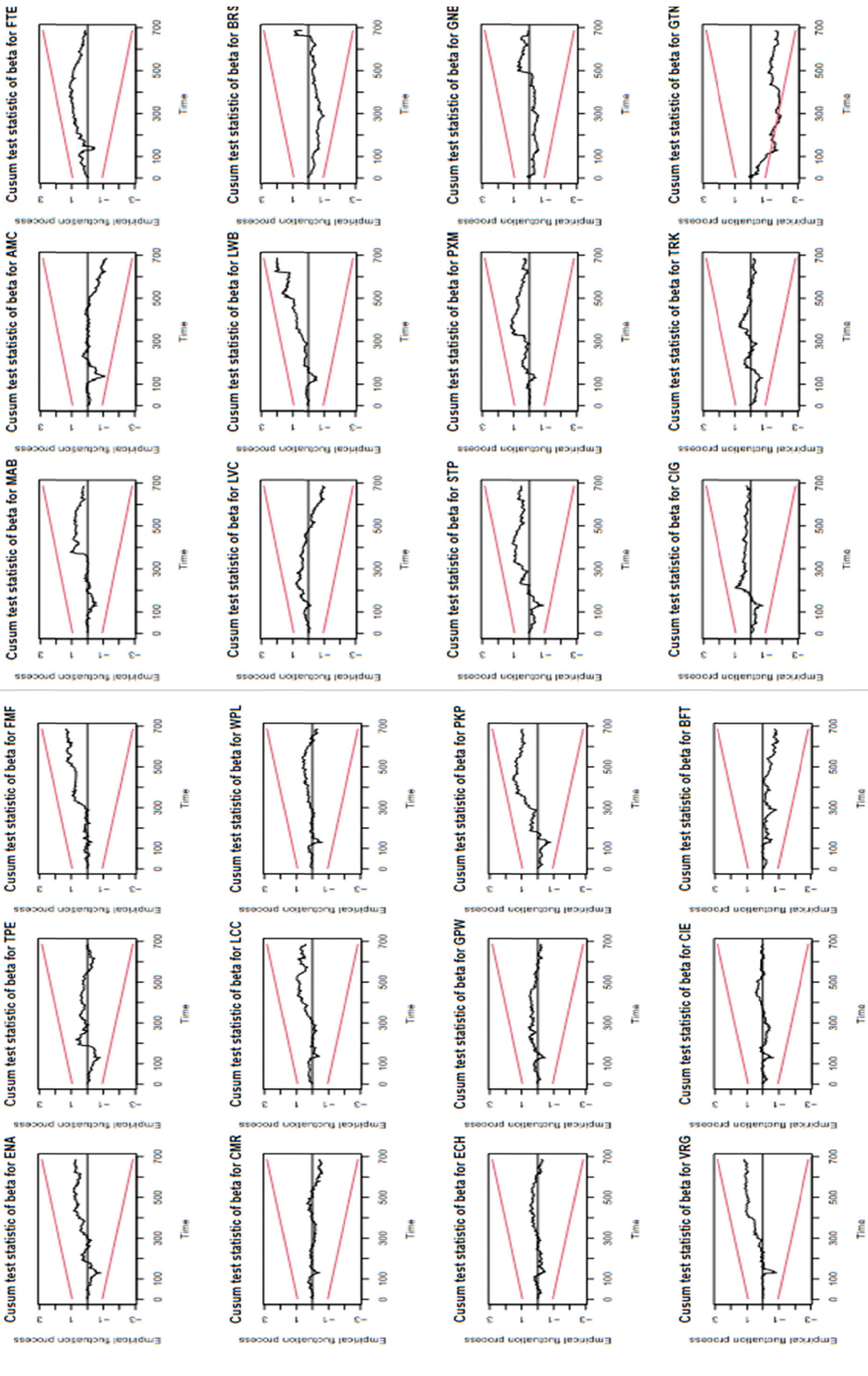
Figure 2
Cusum test



DOI: 10.7172/2353-6845.jbfe.2023.2.1

Figure 2 – continued



DOI: 10.7172/2353-6845.jbfe.2023.2.1

Figure 2 – continued

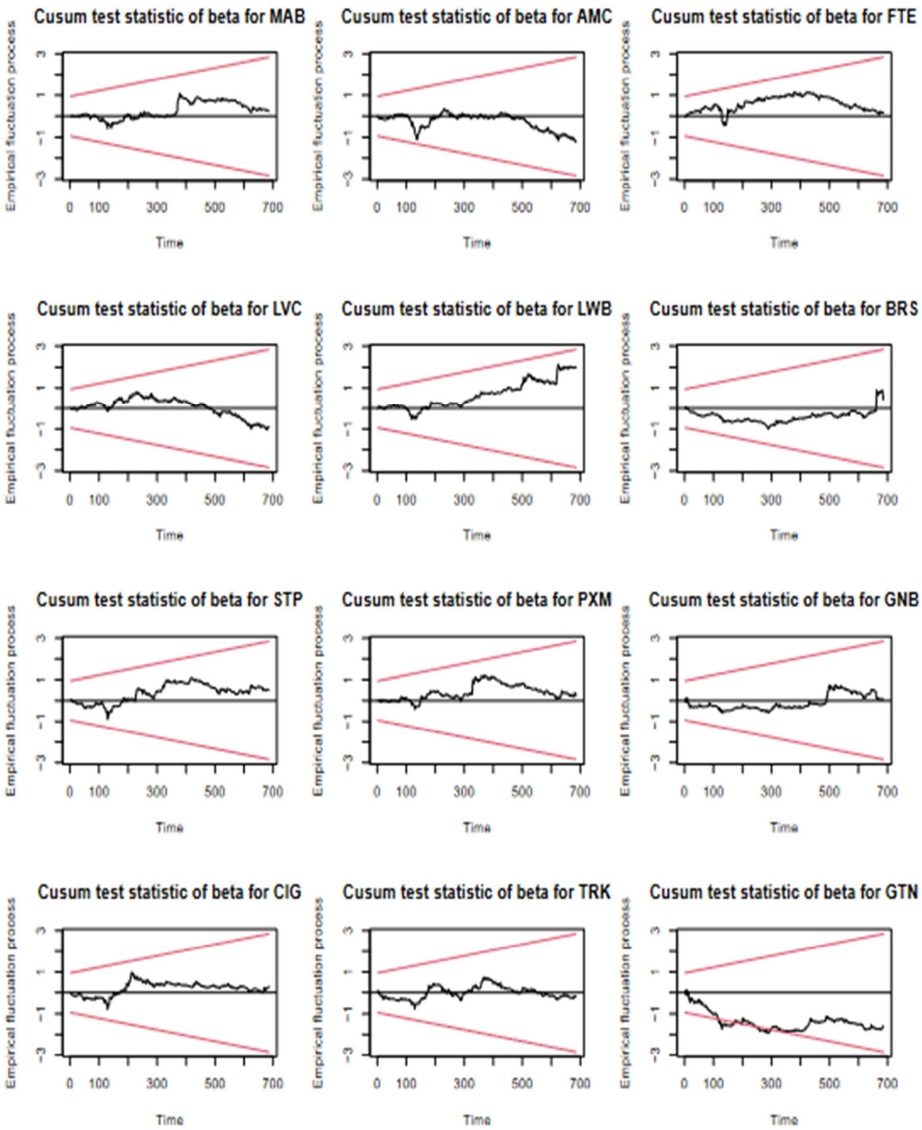


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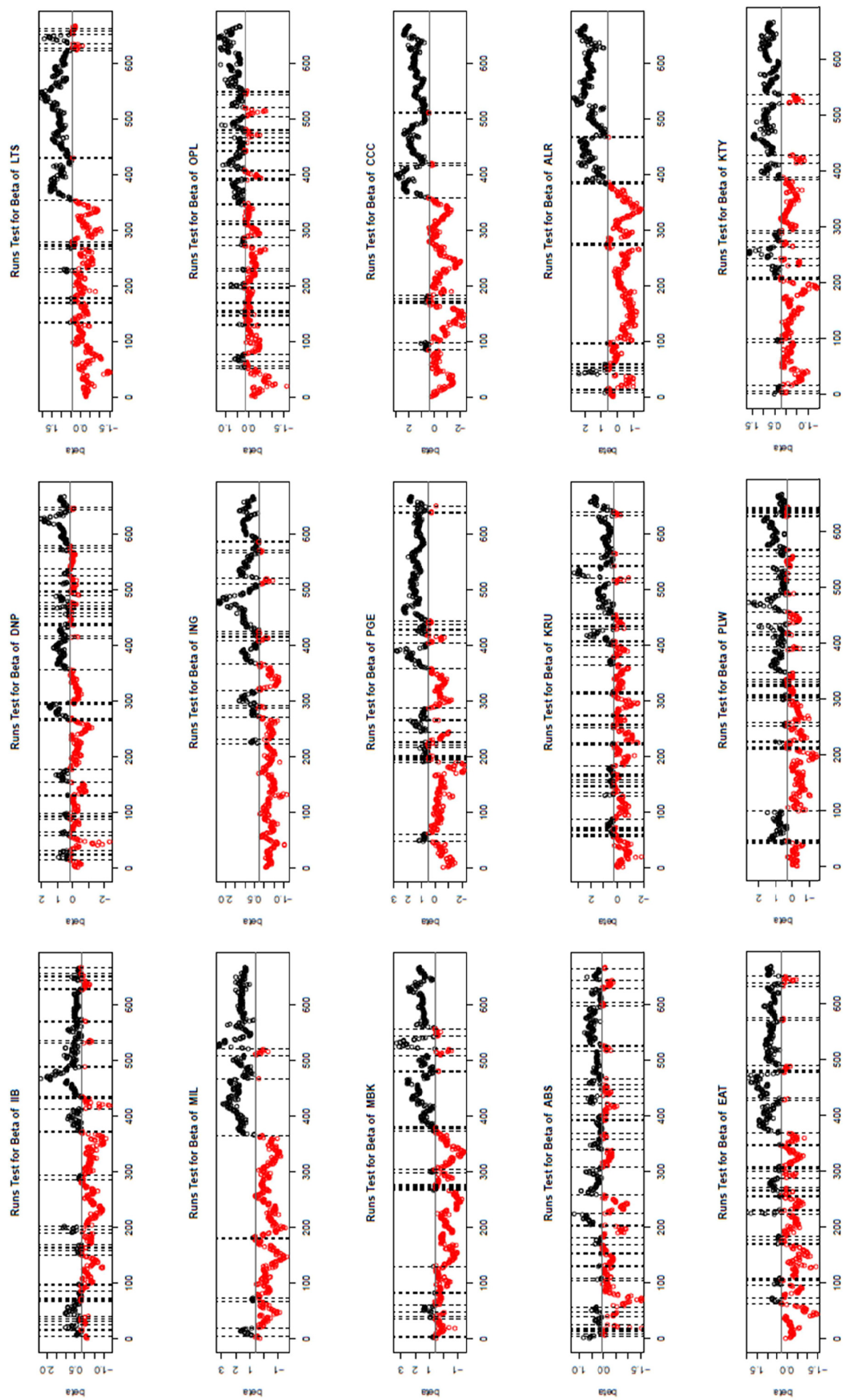
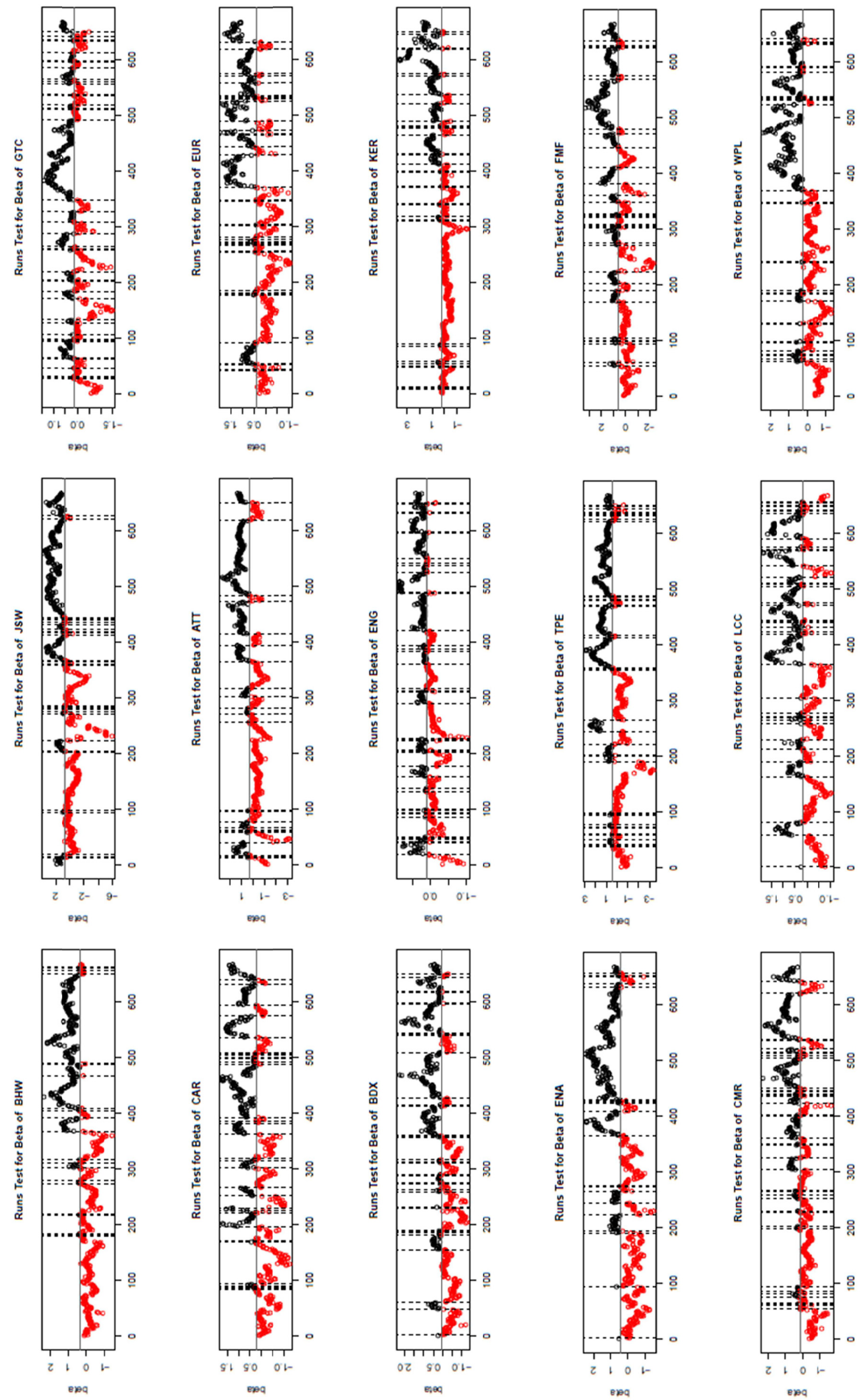
Figure 3
Rolling window run test



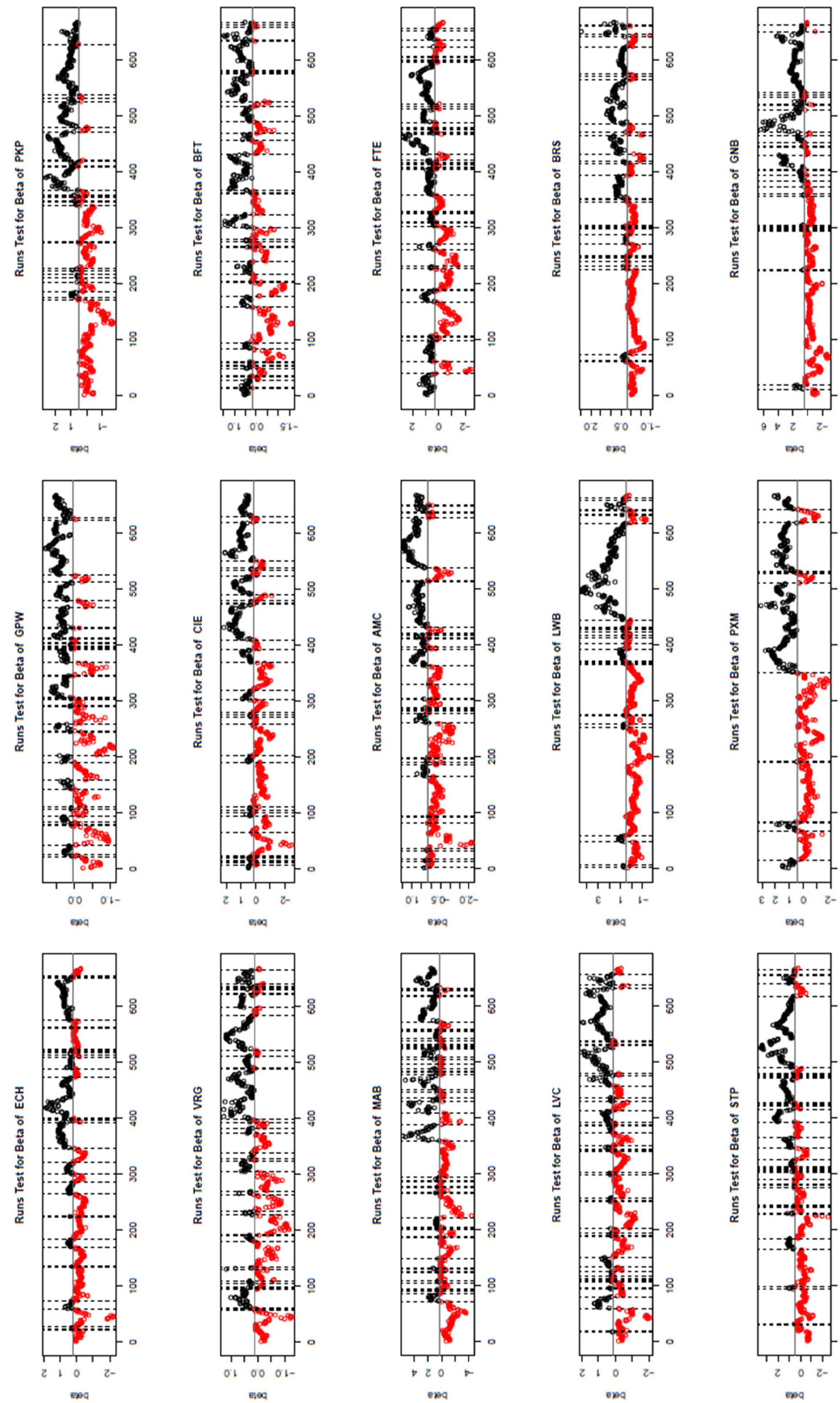
DOI: 10.7172/2353-6845.jbfe.2023.2.1

Figure 3 – continued



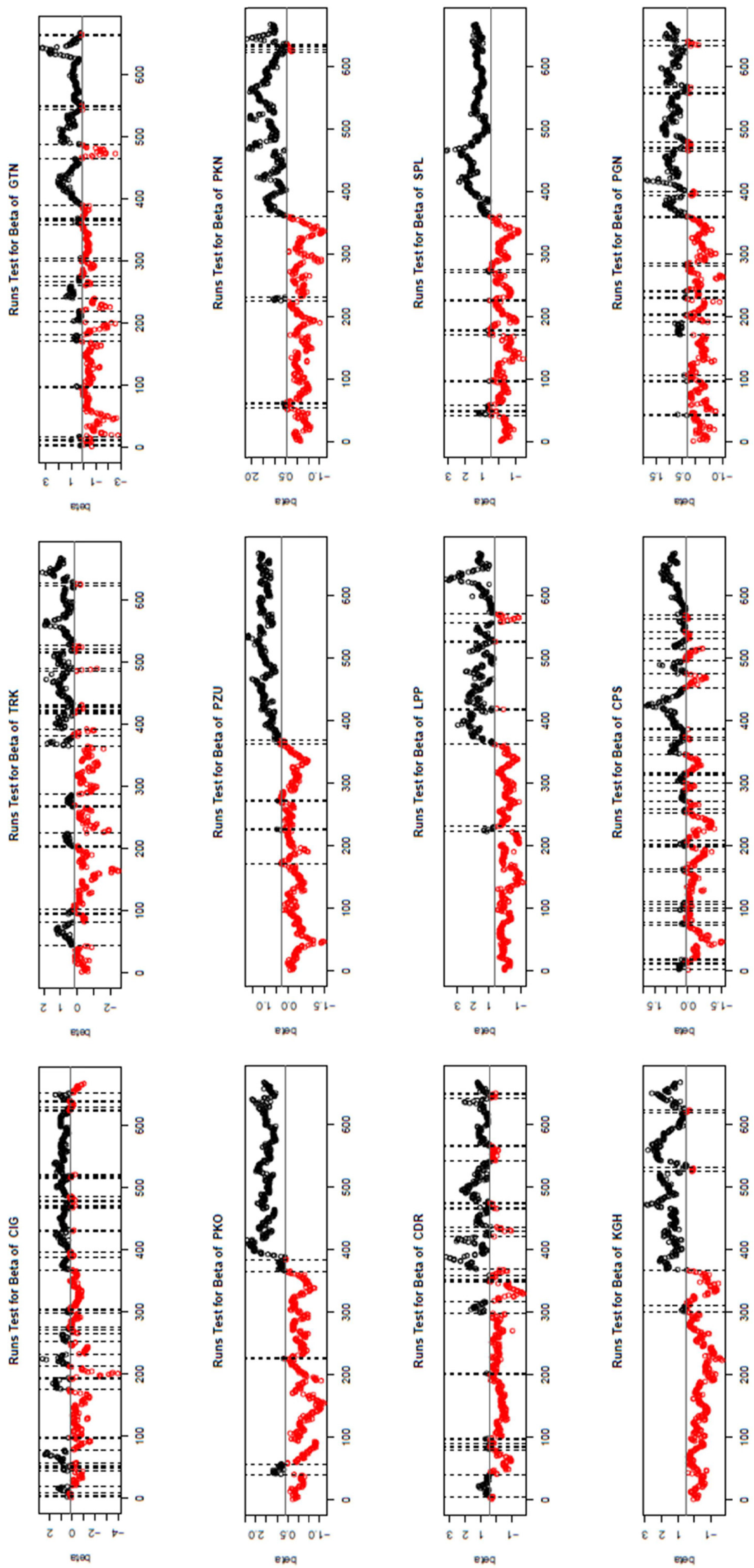
DOI: 10.7172/2353-6845.jbfe.2023.2.1

Figure 3 – continued



DOI: 10.7172/2353-6845.jbfe.2023.2.1

Figure 3 – continued



DOI: 10.7172/2353-6845.jbfe.2023.2.1