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COMPARISON OF COINTEGRATION TESTS FOR NEAR INTEGRATED TIME SERIES DATA WITH STRUCTURAL BREAK

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Abstract

Sample size of data, presence of structural break, location and magnitude of potential break, and having with near integrated process might affect the performance of cointegration tests. Engle-Granger (EG) and Johansen Cointegration tests may have erroneous results since they do not take into account possible structural break unlike Gregory – Hansen (GH) cointegration test. In this study, it is argued that the suitable choice of cointegration tests is quite complex, since outcomes of these tests are very sensitive to specifying these properties.

The performance of cointegration tests is compared to each other underlying properties. This study presents how standard residual based tests- Engle-Granger and Gregory-Hansen- for cointegration can be implemented if series is near integrated, that is close to a unit root process. For assessing the finite sample performance of these tests, a Monte-Carlo experiment showed that both cointegration tests have relatively better size and power properties depend on break point, break magnitude, sample size of time series and the hypothesized value of AR(1) parameter. To illustrate the findings of the paper, a financial data is analyzed. The practitioners should be careful about the hypothesized value of AR(1) parameter which represents dependency degree of the data. If the autoregressive parameters is very close to one and the break magnitude is high, any test is acceptable for moderate to large sample size. However, one might need very large sample size to have a good power and actual size of the test. Additionally, GH test becomes liberal test unlike EG test as the magnitude of structural break increases..

Keywords: Cointegration, Structural Break, Engle- Granger Test, Gregory-Hansen Test

YAPISAL KIRILMALI İÇ BAĞIMLILIĞI YÜKSEK ZAMAN SERİLERİNDE EŞBÜTÜNLEŞME TESTLERİNİN KARŞILAŞTIRILMASI

Özet

Örneklem büyüklüğü, yapısal kırılmanın varlığı, potansiyel kırılmanın yeri ve büyüklüğü ve birim köke yakın prosese sahip olmak Eşbütünleşme testlerinin performanslarını etkileyebilir. Engle-Granger (EG) ve Johansen eşbütünleşme testleri, Gregory – Hansen (GH) eşbütünleşme testinden farklı olarak, olası kırılmaları dikkate almadığından hatalı sonuçlar verebilmektedir. Sözü geçen testlerin çıktıları bu özelliklerin yapısına çok duyarlı olduğundan, bu çalışmada uygun eşbütünleşme testinin seçilmesinin oldukça karmaşık olduğu tartışılmıştır.

Eşbütünleşme testlerinin performansları belirtilen özellikler altında karşılaştırıldı. Bu çalışma, standart hata terimi tabanlı testlerin - Engle-Granger ve Gregory-Hansen- serilerin yüksek iç bağımlılığa (birim köke yakın süreçlere) sahip olduğunda nasıl uygulanabileceğini göstermektedir. Testlerin sonlu örneklem performansları değerlendirildiğinde, Monte Carlo deney sonuçları, her iki testin de kırılma noktası, kırılmanın büyüklüğü, serinin genişliği ve AR(1) parametresi değerleri için anlamlılık düzeyi ve güç değerleri açısından iyi sonuçlar verdiğini göstermiştir. Çalışmanın bulguları finansal veri ile de analiz edilmiştir. Araştırmacılar AR(1) modelin iç bağımlılığını gösteren

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parametrenin değerini test ederken dikkatli olmalıdırlar. Otoregresif modelin parametresinin bire çok yakın çıktığı ve yapısal kırılmanın büyüklüğünün yüksek olduğu durumda her iki test de büyük örneklem genişliği altında uygulanabilir. Ancak testlerin daha iyi güç değerlerine ve nominal anlamlılık düzeylerine sahip olması için çok büyük örneklemlere ihtiyaç vardır. Ek olarak yapısal kırılmanın büyüklüğü arttıkça Gregory – Hansen testi Engle Granger testine göre daha liberal davranışlar sergilemektedir.

Anahtar Kelimeler : Eşbütünleşme, Yapısal Kırılma, Engle- Granger Testi, Gregory-Hansen Testi

1. INTRODUCTION

Most of the economic variables such as inflation, interest rates, exchange rates, real GDP and so forth appear to be highly persistent, and are typically described as unit root or nonstationary processes. Structural break/change in the series sometimes may cause the unit root or nonstationarity problems. Time series with structural changes and unit roots share similar features that make it difficult to discriminate between the two fundamentally nonstationary processes. A well-known drawback of the conventional unit root test is their potential confusion of structural changes in the series as evidence of unit root. Misleading inferences in unit root process may also cause misleading inferences in cointegration process in ignoring an existing structural break. They may potentially fail to reject the cointegration hypothesis if the series have a structural break. In other words, there may be a possibility that the series are in fact cointegrated around the structural break(s), however they are mistakenly classified by noncointegrated. Starting with pioneer study of Perron(1989), Hendry and Neale(1991) and Lee *et al*(1997) examine the performance of testing the null of stationarity when structural break is ignored. Ignoring an existing structural break can give rise to apparent unit roots in stationary time series. Kwiatkowski et al. (1992) propose stationarity tests that take into account of structural breaks. Following this development, many authors, including El-Shagi and Giesen (2013), Zivot and Andrews (1992) and Perron (1997) proposed determining the break point ‘endogenously’ from the data.

Many cointegration tests have been developed in the literature in order to avoid inference problems in misleading decisions in cointegration under structural break. The most widely applied cointegration tests are residual-based ones for the null hypothesis of no cointegration is tested in the sense of Engle & Granger (1987) two-step method. According to Engle & Granger, two time series are cointegrated if a linear combination of the integrated series (I(1)) has a stationary distribution. Gregory- Hansen (1996) and Campos et al. (1996) propose cointegration tests that allow for a structural break of unknown timing. Harris and Inder(1994), Hao (1996), Bartley, Lee and Strazicich (2001), and Carrion-I-Silvestre and Sanso (2006) develop test that examine for the null of cointegration with one structural break in the level and slope. These developed cointegration tests rely upon the strict unit-root assumption which is not easy to argue on economics theory. Although many economic variables are frequently modeled as unit root processes, there is a little a priori information that these variables have an exact unit root, rather than a root close to unity. Since unit-root tests have low power to distinguish between a unit-root and a close to unity under the structural break(s), many econometricians and finance researchers started to discuss the possibility of mild unit root assumption instead of strictly unit root assumption. Phillips (1988) considers near-integrated process that has roots smaller than unity (strongly autoregressive) in his analysis. De Boef & Granato (1999) argue that cointegration tests may lead analyst to conclude mistakenly that the data are cointegrated (or near-cointegrated) when the data are near-integrated. Hjalmarsson & Österholm (2007) investigate the properties of Johansen’s maximum eigenvalue and trace tests for cointegration under the empirically relevant situation of near-integrated variables.

This study contributes to the empirical literature by further re-examining the size and power of the EG and GH tests when the data have deviations from the strictly unit-root assumption because of structural break on the determination of near-cointegrated or noncointegrated. It is assumed that cointegration relationship can be modeled by level shift, level shift in trend and regime shift by near integrated time series. The sensitivity of EG and GH tests to sample size and unity conditions of data is examined and how well these tests can discriminate under the conditions in respect of the study undertaken.

The paper is organized as follows. Section 2 makes a brief description of the EG and GH cointegration tests. Section 3 explains how to construct the experimental design of the study for revealing the impact of break location, break magnitude and dependency degree parameter. Also, results of the Monte Carlo experiment in terms of finite sample size and power are discussed in this section. It is tried to make a clear whether they are conservative or liberal tests. Section 4 gives the results of earthquake and tsunami impacts on Tokyo and Chinese Stock Markets. It is clear that the earthquake has caused a structural change in both markets. The application is performed gradually depending on the magnitude and location of structural break. Finally, some concluding remarks are offered in the conclusion.

2. COINTEGRATION TESTS

Cointegration methodology is the innovation used in time series econometrics in the last decade, by stating the possible existence of long-run equilibrium relationships among nonstationary series (I(1)). Two or more time series are said to be cointegrated if each of the series are individually nonstationary while some linear combination of the series is stationary (I(0)). Cointegration means that many shocks can cause permanent changes in the I(1) series but there is some long-run equilibrium relation. The equilibrium can be distorted in the short run but not in the long run.

Given the linear cointegrating regression model,

$$y_t = \alpha' c_t + \beta' x_t + u_t \qquad (1)$$

where $z_t = (y_t, x_t)'$ is a *m*-vector I(1) time series which may or may not have cointegrating relationship. c_t is a vector of deterministic terms (such as a constant or time trends). $\{y_t\}$ and $\{x_t\}$ are cointegrated if $\{u_t\}$ is stationary. Brief description of the cointegration tests that take into account of structural break is provided in this section.

2.1. Engle-Granger Test (EG)

Cointegration analysis begins with pretests for unit root in the individual series of interest. In brief, the series of interest is first- differenced and regressed on its own lagged levels. If the coefficient on lagged levels is statistically significant different from zero, the data are best characterized as I(1) processes. Since first-differenced series is stationary, the Engle-Granger (1987) methodology can be conducted at two stages. Levels of dependent process are linearly regressed on levels of independent process. The residuals from this regression are also tested for the stationarity using unit root tests. Rejection of the null of residual series obtained from the cointegrating regression has unit root, gives strong evidence of cointegration. For the statistical theory and overview, see Granger (1981, 1983) Engle-Granger (1987), Johansen (1995).

2.2. Gregory-Hansen Test (GH)

Another commonly used test is Gregory-Hansen test (GH), which consider an alternative hypothesis in which the cointegrating vector may be subject to a structural break at an unknown/known time. Gregory – Hansen (1996) analyzed models that arrange, under the alternative hypothesis of cointegration, the possibility of changes in parameters. GH test investigates the determination of the structural breaks in the cointegration analysis in three models such as a break in the level, a break in level in the presence of a linear trend and a break in both level and linear trend.

These models are:

2.2.1. Level shift model (C)

This model, which involves a break in the level, is expressed as below**:**

$$y_t = \mu_1 + \mu_2 DU_t + \beta' x_t + u_t \qquad t = 1,2,\dots,T \qquad (2)$$

μ_1 represents the constant term before the break, μ_2 represents the change in the constant term during the structural break, β' indicates the cointegrating slope coefficient, DU_t denotes a dummy variable which allows break to occur at time τ such that $DU_t = 1$ if $t > [T\tau]$ and zero otherwise. Here *n* is the number of observations, τ is a coefficient which denotes the break period between (0.15*T*, 0.85*T*).

2.2.2. Level shift with trend (C/T)

Level shift with trend model which involves the break in intercept with trend is expressed as below:

$$y_t = \mu_1 + \mu_2 DU_t + \alpha t + \beta' x_t + u_t \quad t = 1,2,\dots,T \quad (3)$$

Model in equation 3 has same parameters as in equation 2, but additionally includes trend variable as t for measuring trend effect.

2.2.3. Regime shift (C/S)

Regime shift model which involves a break in both the intercept and trend (slope of trend line) of the series is expressed as below.

$$y_t = \mu_1 + \mu_2 DU_t + \beta_1' x_t + \beta_2' x_t DU_t + u_t$$
$$t = 1,2,\dots,T \qquad (4)$$

μ_1 , μ_2 and DU_t have the same representation as in level shift model. β_1' represents the cointegrating slope coefficient before the break, β_2' denotes the change in the slope coefficient after the break. Model C/S is different from Model C/T since the former involves trend variable. GH test tries to reveal the cointegrated structure depending on the location of the break.

3. FINITE-SAMPLE EVIDENCE-MONTE CARLO EXPERIMENT

Data generation process (DGP) is conducted using MATLAB (R2011a). The series are generated for three different models which consist of single structural break in intercept, break in intercept and trend and break in intercept and slope of the time series model.

Cointegrated y_t and x_t series are generated from AR(1) and I(1) process with near-integrated values of ϕ=0.9,0.95,0.99 parameter for 50, 100, 200 sample size with 10000 replications. In general, the closer ϕ is to one; the less likely the series are cointegrated. Behavior of u_t series which are produced by equation 1 under consideration have examined depend on stationarity condition. If it is stationary, y_t and x_t series are cointegrated.

In this study, it is assumed that the break date is known or exogenous. The power of the tests is compared depending on part of the series where break has been occurred. The parts of the series are treated as break in the first quarter (0.25T), in the second quarter (0.50T) and in the third quarter (0.75T) of the series. Since the magnitude of the structural break in the series may also affect the power of the tests, the performance of tests is also investigated with 1, 5 and 10 unit break magnitude in corresponding parts of the series.

3.1. Power&Emprical Size Comparison of the Cointegration Tests for All Models

To evaluate the performances of cointegration tests and to compare them to each other, we carried out a simulation separately, for each model. Totally eighty figures, graphics of power and empirical size, are examined in the experiment, but substantial figures are presented in the following sections.

3.1.1. Level shift model

If ϕ is close to unity (ϕ=0.99), then increasing in break magnitude in small sample size 50 leads to decrease power for both test. Impact of structural break which is occurred especially in the last quarter has negative affect both tests' power, but power of EG test has fallen down dramatically in comparison with GH. Increasing the size of the sample from 50 to 100 is not enough to have high power level for each test. To attain such a high level of power, increasing sample size 200 rather than 100 is a good solution for the relatively low levels of ϕ coefficient (for 0.9 and 0.95). However, if ϕ is 0.99, both tests' powers have decreased deeply. Remarkably point is that the shape of the GH test's power is saddle-shaped when ϕ is 0.95 as shown in Figure 1.

In comparing of tests based on empirical size, the empirical size of EG test is increasing if the structural break is in the first quarter and last quarter part of the series. Also, it reaches to 9% level as sample size increases. The empirical size approaches the nominal size as structural break magnitude increases and if it is in the middle of the series, in contrast to GH test, whose empirical size level is at around %2 as sample size and structural break magnitude increase. GH test is liberal in this model under the consideration.

3.1.2. Level shift with trend model

Since trended time series is used in this model, even if sample series of length is 50, increasing ϕ coefficient (almost have a unit root), does not cause any decline rapidly in both tests' power. As magnitude of structural break goes up, so does power of GH test becomes larger than the ones of EG test. However, there is a point at which increasing sample size (from 50 to 200) couldn't suffice to keep the power 80% level especially when ϕ=0.99. The results are shown in Figure 2. As sample size increases, the ϕ coefficient becomes more important for the power of these tests in this model. The power of EG test has negatively affected by magnitude and location (if it is in the middle of the series) of structural break and closeness of ϕ coefficient to unit root whereas power of GH test has negatively affected by just location of the structural break.

According to this model, EG test has the lowest value of empirical size when sample size is 50. As sample size increases, location and magnitude of structural break have no longer significant impacts on the empirical size which has grown to almost 6% level. Growing empirical size means that the discrepancy of empirical size and nominal size is getting bigger. In contrast to EG test, the empirical size of GH test approaches to nominal size under sample size increment regardless of location and magnitude of structural break.

3.1.3. Regime shift with decreasing trend

The series which is generated by simulation consists of decreasing trend component in this model. Because of trend effect, both tests' power is decreasing if the break is especially in the first quarter part of the series as sample size increases. But this decreasing in power becomes dramatic for EG test. It would need a much larger sample size in order to increase the power. The results could be seem in Figure 3.

When behaviors of empirical size of these tests are examined for this model, empirical size of EG test drifts away from the nominal size as the number of sample size increases whereas one of GH test approaches to nominal size. Empirical size of GH test does not affected by location and magnitude of structural break under the regime shift with decreasing trend model.

3.1.4. Regime shift with increasing trend

Both tests have high level power performance (100%) in regime shift with increasing trend model as shown in Figure 4. Power of EG test has been affected by dependency degree of the series (ϕ coefficient) as sample size increases. Besides the magnitude of structural break, the location of the break becomes crucial in this model. The EG test's power is at the deep level if the break has occurred in the last quarter of the series. Increasing sample size makes the GH test more sensitive to location and magnitude of break. The GH test has low power when structural break occurred in the last quarter of the series with 10 unit increment. Increasing the dependency degree of the series from 0.9 to 0.99 does not change this consequences.

Figure 1. Level Shift Model

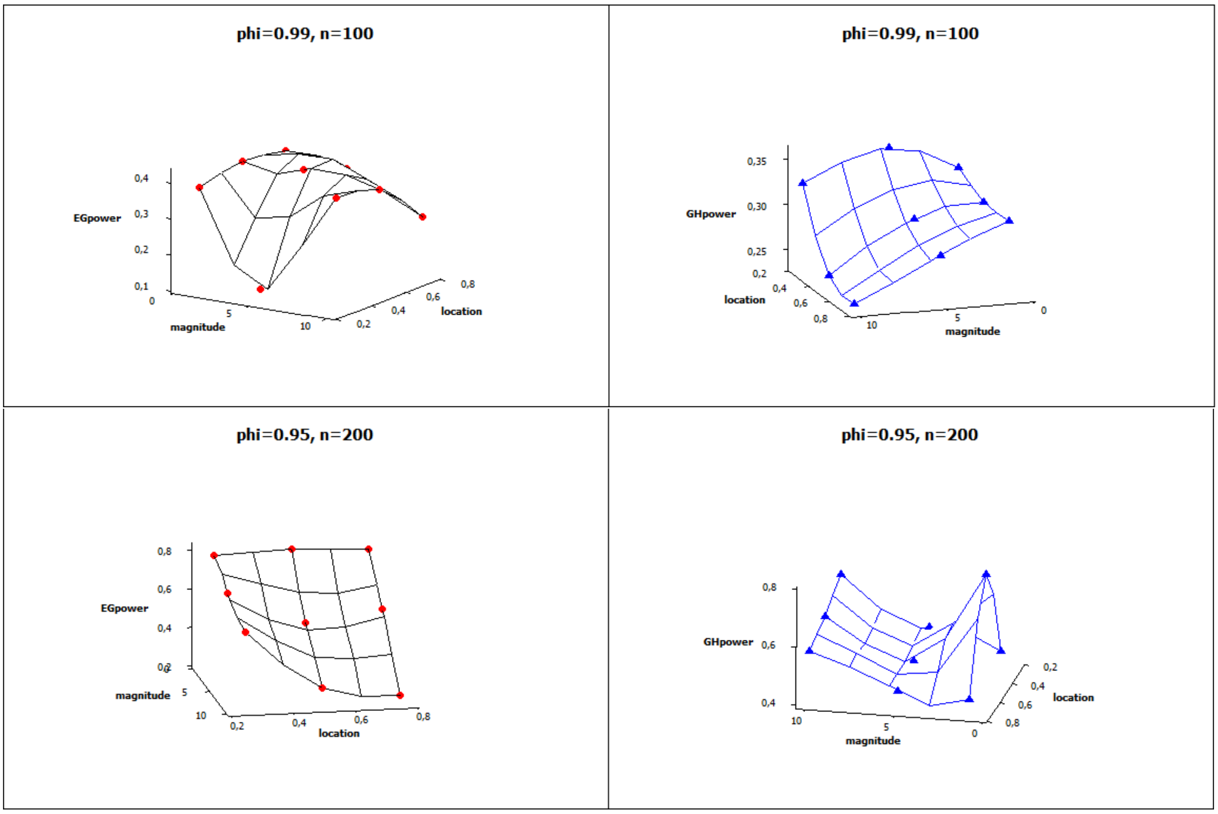


Figure 2. Level Shift with Trend Model

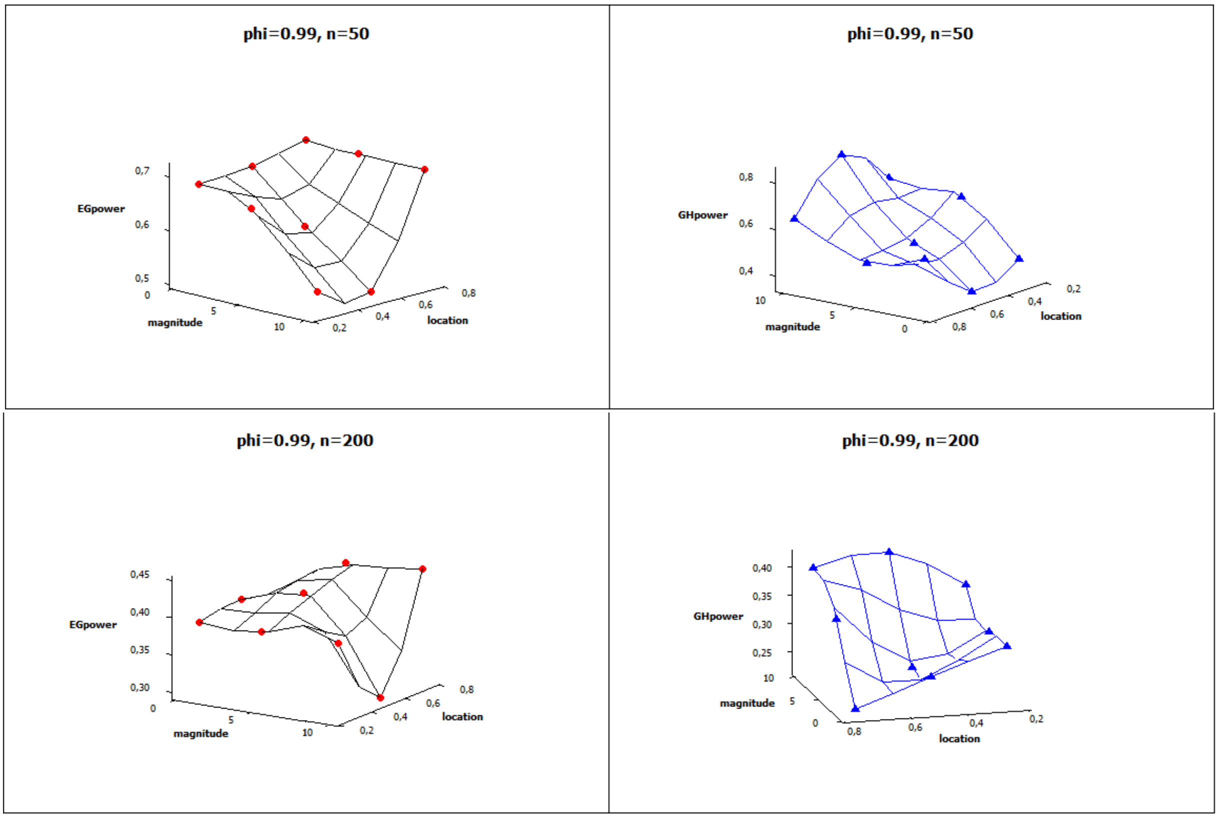


Figure 3. Regime Shift Model (with Decreasing Trend after structural break)

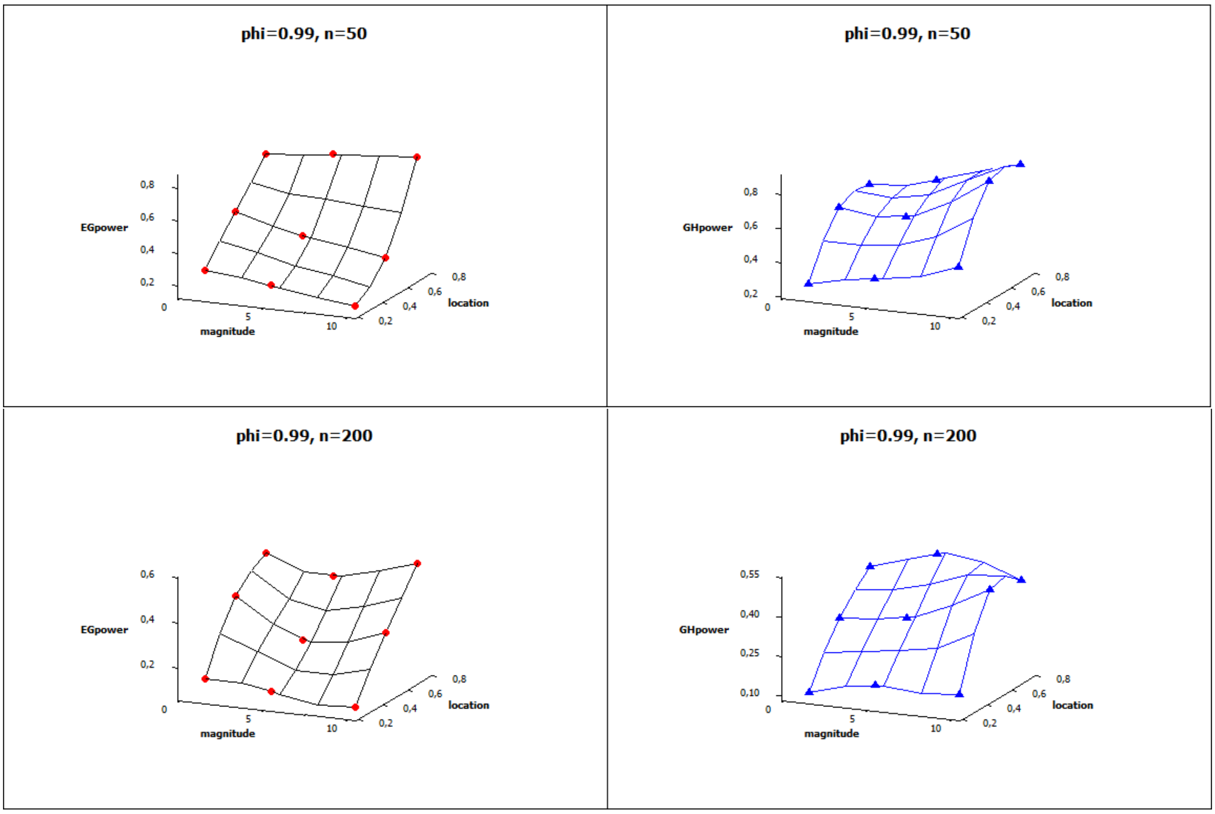


Figure 4. Regime Shift Model (with Increasing Trend after structural break)

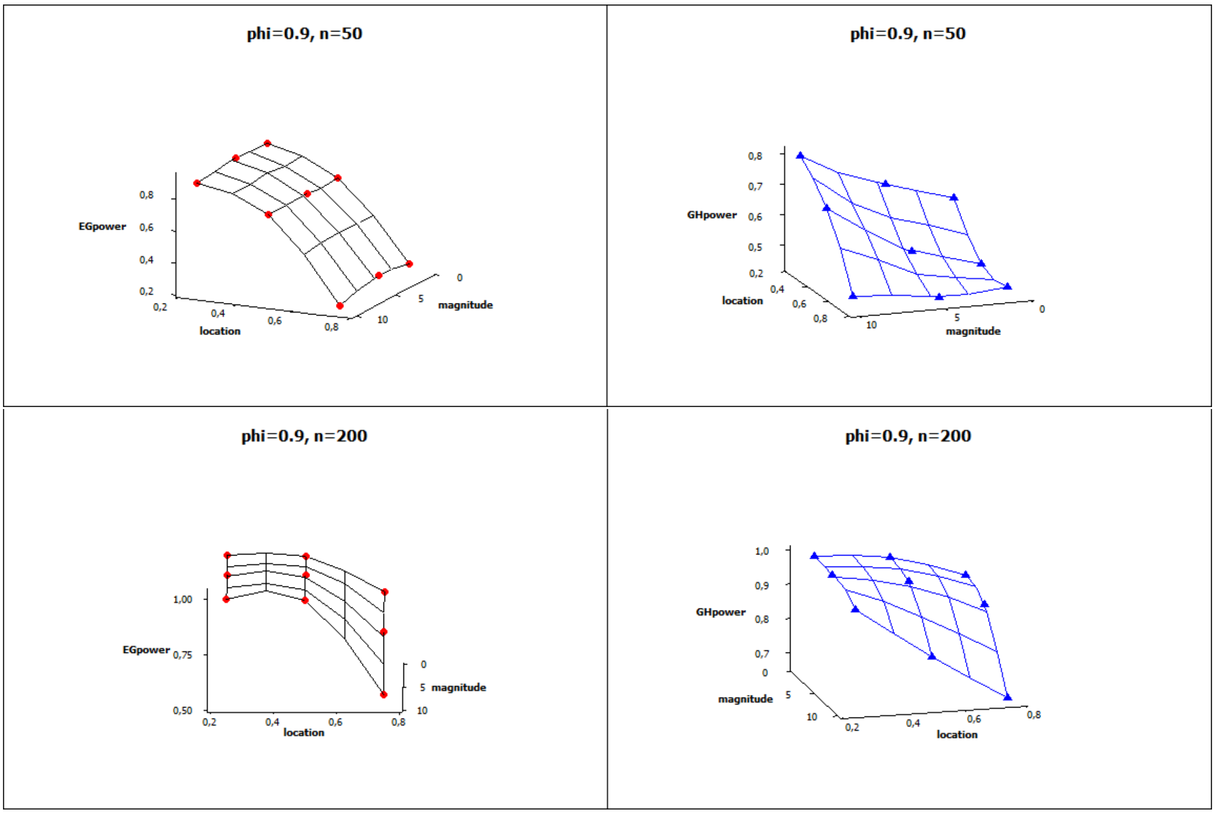
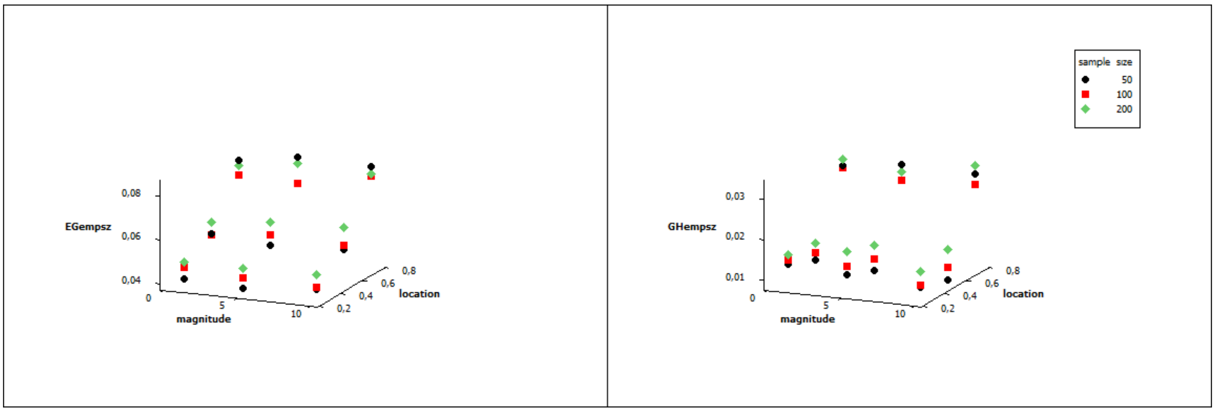


Figure 5. Empirical size comparison of the tests for regime shift model (with increasing trend)

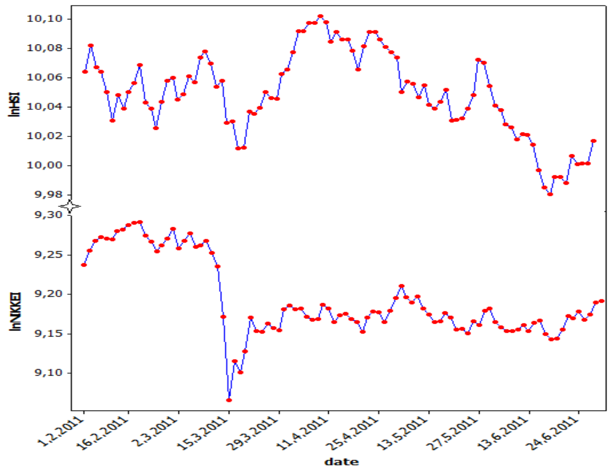


Empirical size comparisons of the tests for regime shift model are shown in Figure 5. According to Figure 5, getting larger sample size does not make any difference in tendency of empirical size. According to location of structural break becomes important for EG test. If the break has occurred in the first quarter part of the series, empirical size of EG test becomes very close to nominal size. Reasonable agreement between empirical and nominal size is relevant for GH test, but the location of the break. If the break has occurred in the last quarter part of the series, empirical size of GH test approaches to nominal size.

4. EMPIRICAL ILLUSTRATION

To illustrate what is stressed in this study that it must be taken account of not only location but also magnitude of structural break before performing cointegration tests (EG and GH), Tokyo Stock Market and Chinese Stock Market, which is thought cointegrated with Tokyo stock market, daily data have been used in this paper. The data covers a period of six month period starting from Feb.1st, 2011 and ending in Jan. 30th, 2011. The data of these market time series are plotted in the graphs at level in Figure 6.

Figure 6. Time series plot of earthquake impact on Tokyo and Chinese stock markets.



The negative impact of the March 2011 earthquake and tsunami on Tokyo Stock market has been particularly felt on the 15th of March which is the second working day after the devastating earthquake in Japan. The NIKKEI dropped over 10% to finish at 8605.15, a loss of 1015 points. Japan's massive earthquake and tsunami have sent shockwaves through China's economy. Japan was one of China's most important trade partners, accounting for about 8 percent of China's total exports, while China sourced 13 percent of its imports from Japan. Trade between the two countries was definitely be affected in the short term. Although the quake also reduced Japans' imports from China, overall the spike was relatively modest and short-lived. The later and weaker impact has been showed up in HSI stock market.

To evaluate the influence of the location of structural break, the data is examined as separating into three sets: The first set contains the structural break which is in the first quarter part of the series (T_1=94), the second one covers the structural break in the middle of the series (T_2=50) and the third one is included it in the last part of the series (T_3=37). The data is analyzed into three models (level shift, level shift with trend and regime shift). According to Zivot Andrews unit root test, the structural break has occurred in the 15th of March. The EG test results showed that the series are not cointegrated regardless of location of the structural break. [the first quarter part (p-value=0.6556), middle (p-value=0.8471) and the last part of the series (p-value=0.8638)]. According to GH test results, the series are cointegrated if the structural break has occurred in the first quarter part (with ϕ=0.941), in the middle part (with ϕ=0.932) and in the last quarter part of the series (with ϕ=0.852) p-value<0.001, p-value<0.001, p-value<0.025), respectively.

5. CONCLUSION

In this study, effects of systematic pattern of time series data on cointegration tests is investigated. This study revealed that in the presence of structural break, the specification of the systematic pattern is also so important in performance of EG and GH tests. It has been shown that in the presence of a structural break, these tests' conclusion about cointegrating relationship can be biased toward not rejecting it when the near integrated time series data is used. In a finite sample it is quite difficult to distinguish between an integrated variable and a "near-integrated" variable. Therefore, if a priori knowledge of a structural break exists is evident in eyesight, one should use the GH cointegration test.

The magnitude of the structural break is also important for choosing the cointegration tests. If there is a slight one unit drop in the series (i.e. drop from 100 to 99), researchers can choose both tests for analysis, because the drop does not cause significant effect on the series. However, when the drop is around 10 unit, the effect of structural break must not ignore, then the GH cointegration test must be preferred.

Identifying the model type (level shift, level shift with trend and regime shift) is the also important part of cointegration analysis especially with near-integrated data, because existing of trend component in the series may block to distinguish the structural break. In this circumstance, there need to take larger sample size.

The increasing of dependency parameter (ϕ) have negatively impact on level shift model. In level shift model with trend, EG test results has more sensitivity to the location and high dependency degree, whereas GH test has affected by just the location of the structural break. When the series fits to regime shift model with increasing trend, the location of structural break become considerable for both test, but the power of EG test is decreasing deeply when the break has occurred in the last part of the series.

GH test becomes liberal test, so its power does not quickly decline unlike EG test as the magnitude of structural break increases

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