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Unit Root Dynamics in Financial Time Series: A Comparative Study of Parametric and Non-Parametric Testing Frameworks

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ABSTRACT

The study explores unit heterogeneity implication in financial time series analysis and investment decision guide, using some parametric and non-parametric tests that includes Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS), i.e one parametric unit root test (ADF) against two non-parametric unit root test (PP and KPSS). The study selects 5 US financial and macroeconomic variables spanning from January 2020 to December 2023 (monthly series) that includes US Dollar Index, S&P 500 Index, NASDAQ, Bond Yield, and Consumer Price Index for all urban consumers. The findings underscore the heterogeneous nature of unit roots in financial time series, with differences in persistence, integration order, and mean-reverting properties across variables, which reinforces the need for a multi-test approach combining parametric and non-parametric techniques to achieve robust stationarity inference.

INTRODUCTION

The analysis of financial time series has become an integral part of econometrics and finance and has metamorphose to the standing pillar for modelling, forecasting, and interpreting various economic and financial events. Macroeconomic indicators and financial time series data like inflation, interest rate, and exchange rate are the foundation of financial econometrics and economic analysis. Valid decision and inference can only be reach if in the modelling approach the statistical properties of the series is well comprehended. An important parameter in the statistical properties of a financial time series is stationarity, which defines whether the mean, variance and autocovariance of the series is constant over time. However, a lack of stationarity can significantly complicate econometric analysis, as traditional statistical technique often assumes the underlying data is stationary. A non-stationary series implies the presence of unit root, and the series shock has persistent or even permanent effect, which translates to stochastic trend rather than the power of mean reversion. A non-stationary financial time series indicates that following disturbances the series may not return to a long-term equilibrium, for example stock prices are always non-stationary, which is consistent with the random walk model that prices are hardly predictable over time (Fama,1970). Identifying the data generating process of a series is fundamental in determining the appropriate analytical technique to be adopted. A non-stationary series may undergo processes as differencing, cointegration analysis and or error correction term to make a valid decision and inference (Engle & Granger, 1987).

The inspiring work of Dickey and Fuller (1979), and Phillips and Perron (1988) has become the corner stone for the detection of unit root in econometrics. However, these tests are considered parametric methods due to their explicit assumptions on the stochastic properties of the series that includes linearity of the time series and the normality of the errors. However, these tests have limitations when applied to real financial variables, because of volatility clustering, heavy and fat tails, drifts and structural breaks all of which can violate the assumptions of the parametric tests and hindered their objectivity.

Financial time series are heterogenous in nature because of market diversity; various classes of financial assets traded in various sectors and regions. The market diversity involves various degree of volatility, structural behavior and persistence across the financial time series. According to Chang *et al.* (2010) stock prices in emerging markets may tend to have more persistence and volatility due to regulatory framework and market efficiencies. Likewise, economic fundamentals and monetary policy may trigger stability of exchange rate between emerging and developed economies. The heterogeneity of financial time series may complicate its analysis, as such standard unit root test may fail to capture the dynamism of the dataset.

The limitations of the parametric unit root test have let to the development of an alternative approach known as parametric unit root test; it is considered a robust alternative for detecting unit root in financial variables. The test does not rely on the assumption of the functional form of the data, but rather it estimates the properties of the time series directly which is more unique to the

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heterogeneity and complexity financial time series. KPSS unit root test computes the test by checking for the presence of a deterministic trend or level providing complementary insight to the parametric method.

It is very important to know the data generating process of a series; its significance is beyond theoretical underpinning but rather have practical implications. It is crucial to aspects such as risk management, portfolio optimization, and macroeconomic forecasting. In stock market, trading strategies can be affected by the presence of unit root. Prices in financial market are influenced by stochastic trend rather than mean reverting behavior. Moreover, in policy scenarios policy makers must consider unit root heterogeneity while formulating monetary and fiscal polices as sit affects macro-economic variables like interest rate, inflation, GDP in the long run.

The study is aim at providing a detail comparison on parametric and non-parametric unit root heterogeneity in financial time series. The study will explore the theoretical foundation, empirical underpinning, and practical guidelines. The hallmark of the study is to address the critical gaps from the literature with the aim of providing appropriate method in the use of these tests. The analysis will use both real data to cover a wide range of financial assets, market and time. The analysis will provide a comprehensive evaluation of the tests in detecting unit root heterogeneity among financial time series.

Additionally, the study explores unit heterogeneity implication in financial time series analysis and investment decision guide, by emphasizing on the significance of adapting econometric method to the unique features of financial time series. The study will be significant by proving valuable insight for academics, investors, and policy makers.

LITERATURE REVIEW

Revealing the data generating process of a financial time series remain the foundation of empirical analysis. The fundamental question here is theses series follows a stochastic process (unit root) or a stationary process around a mean or a deterministic trend. The most widely used unit root test in financial time series are ADF, PP and KPSS which are parametric and non-parametric in their approach.

In most of the empirical works the tests are jointly used to provide more reliable evidence on the degree of persistence in financial data (Harris & Sollis, 2003).

Exchange Rate and Purchasing Power Parity

Purchasing power parity remains one of the earliest and most persistent application of ADF, PP and KPSS.

Bakker (2024) examine the power of mean reversion in a bilateral exchange rate series using ADF, KPSS and found that nominal exchange rate exhibit random walk process, while Doganlar & Ozmen, (2000) adopted ADF and PP on real exchange rate of 18 developing economies and found limited evidence of stationarity, meanwhile adopting KPSS shows frequent rejection of stationarity hypothesis, thereby reinforcing the ADF and PP findings (see Lothian & Taylor, 1996; Rapach & Wohar, 2002) In the context of developing economies, the work of Akinbobola (2015) and Udoh and Ebong (2016) shows evidence of random walk process among nominal exchange rate series, while KPSS shows continues rejection of the null.

Stock Prices, Returns and Market Efficiency

Literature on stock market efficiency uses ADF, PP and KPSS in determining the data generating process of stock price and returns base on market efficiency hypothesis.

ADF was applied to determine US stock market returns by Guo (2023) and confirmed that it follows a random walk process, while the stock returns are stationary. However, in anlysing Indian stock market, Mishra and Smyth (2010) applied ADF, PP and KPSS test and confirmed that it also follows a random walk model with an integration of order one. Moreover, Uddin and Alam (2007) studies the south Asian stock market and reveal heterogenous outcome, ADF and PP couldn't reject the null of unit root while KPSS results accepts the null stationarity in returns.

Interest Rate and Term Structure

Unit root test with regards to interest rate are mostly non stationary with short term rates and stationery with long term rates. For instance, Hall *et al.* (1992) confirmed non stationary in US treasury yields, while Panopoulou (2005) confirmed that short term rates are stationary with ADF and PP, while KPSS reveals unit root for long term rates. Other empirical evidence includes the work of Rogoff *et al.* (2024) in which he adopted ADF and PP confirmed unit root for long-term yield while KPSS shows stationarity for short term interbank rates.

Commodity and Energy Prices

Unit root test has been widely used in commodity and energy market, particularly oil price in determining the integration properties.

Pícha et *et al.* (2024) found a heterogenous results in oil prices where ADF and PP shows unit root and KPSS test also rejects the null of stationary. However, in the Asian oil market Narayan and Liu (2015) finds a similar result. Higgs and Worthington found a non-stationary process in electricity price using ADF and PP while KPSS also rejected the null of stationarity

Cryptocurrency Markets

Adoption of trio unit root in crypto markets produced a mixed result, the work of Urquhart (2016) examine bitcoin returns and reports that ADF and PP confirms non stationary at level consistent with market inefficiency, while Bariviera (2017) and Naderajah and Chu (2017) confirmed non stationary in bitcoin prices and KPSS confirm stationarity in the return series.

Emerging Markets Financial System

The literature in emerging markets produced a conflicting result between ADF, PP and KPSS. Okonko *et al.* (2015) applied unit root test on stock index, exchange rate and interest rate in the Nigerian market and found evidence of unit root for all series, while Ibrahim and Aminu (2002) conducted the test on some selected west African markets and found evidence of unit root using ADF and PP, while KPSS suggest stationarity for the series.

Unit Roots and Stationarity in Financial Time Series

According to Nelson and Plosser (1982), a financial time series is said to be stationary if its mean E (y_i), variance var y_i and autocovariances $\gamma(k) = E(y_i - \mu)(y_{i-k} - \mu)$ is constant over time. However, a non-stationary series exhibit unit root, showing persistent effects of shocks rather than power of mean reversion. The autoregressive process of order 1 is specified as:

$$y_t = py_{t-1} + \varepsilon_t, \ \ \varepsilon_t \sim IID(0, \delta^2)$$

Where p is the coefficient of the AR and is a white noise error term, if p=1 a random walk process will have a unit root as $y_t = y_{t-1} + \varepsilon_t$

the above implies that the variance of y_t increases with time, which shows that the series is non-stationary and exhibit a mean reverting process

The efficient market hypothesis theory has shown that financial time series such as exchange rate and stock prices follow a unit root process (Fama, 1970). However, some financial variables like inflation display the tendency of mean reversion, implying that not all economic series exhibit unit root behavior (Lo & Mackinlay, 1988).

MATERIALS AND METHODS

The study aims at examining the heterogeneity of unit root among some selected financial variables using some parametric and non-parametric tests that includes Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). The issue of unit root among financial variables is a well-established fact in econometrics which has significant implication in modelling, forecasting, and policy scenarios. Each test provides a different perspective on stationarity, allowing for a comparative evaluation of their performance in detecting unit roots.

Some of the factors that accounts for unit root among financial variables include varying degrees of persistence, structural breaks, or different stochastic processes governing the series (Perron, 1989; Bai & Ng, 2004), understanding these factors does not only help in revealing the data generating process of the series but also help in selecting appropriate econometric models and the problem of spurious regression (Granger & Newbold, 1974).

Parametric and non-parametric unit root test differ in the assumption they made with regards to the error term, while the parametric classifications assume a specific structure for the autocorrelation in the errors and use sufficient lag to soak up the serial correlation, the parametric test corrects for serial correlation and heteroskedasticity after the estimation by using a long run variance estimator.

This study utilizes one parametric unit root test (ADF) against two non-parametric unit root test (PP and KPSS) to achieve it objectives.

Data and Variables

The study selects 5 US financial and macroeconomic variables spanning from January 2020 to December 2023 (monthly series). The variables are

US Dollar Index (DXY), a trade-weighted measure of the dollar's value relative to a basket of major currencies, obtained from the Federal Reserve Economic Data (FRED), using end-of-month values.

S&P 500 Index (SPX), measured as the monthly closing level, sourced from Yahoo Finance

NASDAQ Composite Index (NADJ), representing US technology and growth equities, measured as the monthly closing level from Yahoo Finance.

10-Year US Treasury constant maturity rate, serving as the benchmark long-term bond yield, taken from FRED series, expressed as monthly averages of daily figures.

Consumer Price Index for All Urban Consumers: All Items (CPI), not seasonally adjusted, sourced from the U.S. Bureau of Labor Statistics.

All index and exchange rate series are transformed into natural logarithms to mitigate heteroskedasticity and to allow interpretation of results as percentage changes, while the bond yield is retained in levels.

Models

Parametric Unit Root Test

Dickey and Fuller (1979) has designed a widely use parametric test for unit root, which follows the below regression:

$$\Delta y_t = \alpha + \beta_t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-1} + \varepsilon_t$$

Where α is constant

β_t is a deterministic trend

γ is the coefficient that determine stationarity

P id the lag difference for serial correlation

ε_t is a white noise error term

The null hypothesis is defined as:

H_0: γ = 0 (Unit Root)

H_1: γ < 0 (Stationary)

However, to account for autocorrelation, the test has extended it test by adding lagged difference terms.

Non-Parametric Unit Root Test

Phillips – Perron (PP) Test: this test was developed to address the short comments of ADF by accounting for heteroskedasticity and autocorrelation in the error term; as such standard error of the test statistics is specified as:

$$Z\gamma = \left(\frac{\hat{\gamma}}{SE(\hat{\gamma})}\right) - \left(\frac{1}{2} \mathrm{T} \lambda_0^{-1} \delta^2\right)$$

Where γ_0 is the long run variance of the error term ε_t

However, the non-parametric test has a limitation of low power in small samples

Kwiatkowski – Phillips – Schmidt – Shin (KPSS) the

KPSS test (Kwiatkowski *et al.,* 1992) reverse the null hypothesis to stationarity as:
H_0: Stationary
H_1: Unit Root
γ_t is specified as
$\gamma_t = r_t + \eta_t$
Where r_t is a deterministic trend
η_t follows a stationary process.
According to Caner and Killian (2001) the KPSS test is highly sensitive to heteroskedasticity, which can lead to false rejection of stationarity. The test statistics is base on the residual variance as:

$$\eta_t = y_t - X_t\hat{\beta}$$

Where is the deterministic component and the LM statistics is described as:

$$\lambda = \sum_{t=1}^{T}\delta_t^2 \Big/ T^2$$

RESULTS AND DISCUSSION

Augmented Dickey-Fuller (ADF) Test

From table 1, the ADF test shows that all financial time series examined in this study have unit roots at levels, with the exception of NADJ and Bond, which show marginal stationarity. Exg, S&P, NADJ becomes stationary at first difference, suggesting an integration order of I(1). However, CPI requires second differencing, confirming its integration order as I(2).
Base on empirical findings, stock prices, exchange rates, and interest rates tend to follow random walks, necessitating differencing for stationarity (Nelson & Plosser, 1982; Campbell & Shiller, 1987). However, the second-order integration of CPI is indicative of inflation persistence, which has been widely documented in macroeconomic literature (Baum *et al.,* 1999).

Phillips-Perron (PP) Test

This test accounts for heteroskedasticity and serial correlation. From table 2, it supports the ADF results, confirming the non-stationarity of most series at levels. However, the PP test exhibits more negative test statistics, especially for Exg and S&P, implying stronger evidence of unit roots. This difference arises from the test's ability to correct for autocorrelation and heteroskedasticity, leading to more efficient estimates in finite samples (Phillips & Perron, 1988).

KPSS Test: Contrasting Results and Structural Implications

Form table 3, the results indicate that all series except Bond reject the null at levels, confirming non-stationarity. However, Bond remains stationary at levels according to KPSS, contradicting ADF and PP. This suggests mean-reverting behavior in bond yields, a finding consistent with term structure models in fixed-income markets (Diebold & Li, 2006).
The difference in detecting unit root between the parametric and non-parametric unit root test is due to issues of structural breaks or regime shifts that traditional unit root tests fail to capture. Previous studies suggest that ignoring such breaks may lead to misleading conclusions about stationarity (Zivot & Andrews, 1992). The current findings reinforce the argument that using a single unit root test may lead to biased inferences, emphasizing the need for a combined testing approach (Perron, 1989; Kapetanios *et al.,* 2003).

Economic and Econometric Implications of Unit Root Heterogeneity

Implications for Forecasting and Model Selection

From econometric perspective, estimating an OLS regression without variable transformation may result to haven spurious regression parameters. Given that most variables are not level stationary, econometric models should be estimated in first difference or through a cointegration techniques (Engle & Granger, 1987). For a series that is integrated of higher order a cointegration of same order is necessary (Johansen, 1995).
The stationarity of bond yields at levels (as per KPSS) suggests that mean-reverting models such as autoregressive (AR) models or term structure models may be more appropriate than difference-based models. This finding is particularly relevant for bond pricing and monetary policy analysis (Diebold & Li, 2006).

Theoretical Justification for Unit Root Heterogeneity

According to Baillie *et al.* (1996) the heterogeneity in

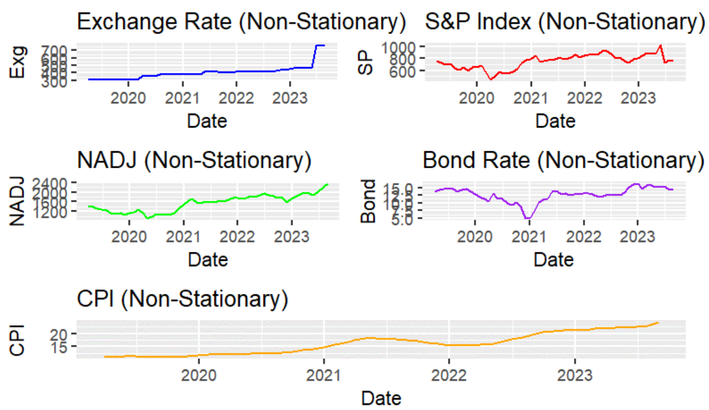

Figure 1: Series Plot at Level

stationarity across financial time series is theoretically supported by models of long memory and fractional integration. Some financial variables exhibit fractional integration ($0 < d < 1$) rather than strict I(0) or I(1) behavior. This suggests that time series may exhibit mean-reverting properties in the long run while behaving like unit root processes in shorter horizons. Such behavior has been observed in inflation rates, interest rates, and exchange rates.

Furthermore, macroeconomic shocks, regime shifts, and policy interventions contribute to nonlinear unit root behavior, necessitating the use of threshold autoregressive (TAR) or smooth transition autoregressive (STAR) models (Enders & Granger, 1998).

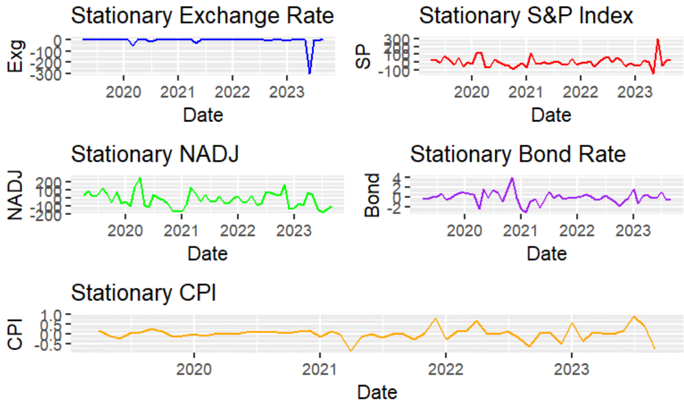

Figure 2: Series Plot at First Difference

Table 1: Augmented Dickey-Fuller (ADF) Test Results

Variable	Level Test Statistic	p-value	First Difference Test Statistic	p-value	Second Difference Test Statistic	p-value	Stationarity Status
Exg	-2.4584	0.3572	-5.2240	0.01	-	-	First Difference
S&P	-3.2167	0.0939	-6.2618	0.01	-	-	First Difference
CPI	-3.1551	0.1091	-3.5236	0.0478	-5.9475	0.01	Second Difference
NADJ	-4.2618	0.01	-5.7133	0.01	-	-	First Difference
Bond	-3.5203	0.0480	-4.0832	0.01	-	-	First Difference

Table 2: Phillips-Perron (PP) Test Results

Variable	Level Test Statistic	p-value	First Difference Test Statistic	p-value	Second Difference Test Statistic	p-value	Stationarity Status
Exg	-10.102	0.5115	-55.224	0.01	-	-	First Difference
S&P	-15.485	0.1842	-64.974	0.01	-	-	First Difference
CPI	-10.030	0.5159	-15.333	0.1927	-59.475	0.01	Second Difference
NADJ	-8.0533	0.6361	-37.133	0.01	-	-	First Difference
Bond	-7.2474	0.6851	-40.832	0.01	-	-	First Difference

Table 3: KPSS Test Results

Variable	Level Test Statistic	p-value	First Difference Test Statistic	p-value	Stationarity Status
Exg	1.0275	0.01	0.29385	0.1	First Difference
S&P	0.81514	0.01	0.12003	0.1	First Difference
CPI	1.3743	0.01	0.26729	0.1	First Difference
NADJ	1.2744	0.01	0.2669	0.1	First Difference
Bond	0.43986	0.05997	-	-	Level

CONCLUSION

The findings underscore the heterogeneous nature of unit roots in financial time series, with differences in persistence, integration order, and mean-reverting properties across variables. This reinforces the need for a multi-test approach combining parametric and non-parametric techniques to achieve robust stationarity inference.

Future research should explore

Structural breaks and nonlinear unit roots using models such as the Zivot-Andrews or Bai-Perron tests.

Fractional integration techniques to capture long memory properties in financial markets.

Regime-switching models to better understand stationarity dynamics in the presence of policy shocks or market crises.

By integrating these advanced econometric techniques, researchers can enhance model accuracy and improve economic forecasting, particularly in financial time series analysis.

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