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Linearity and stationarity of G7 government bond returns

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Abstract

This study investigates the linearity and stationarity properties of government bond returns for the G7 economies. Our results from Luukkonen et al. (1988) linearity test reveal the nonlinear nature of all of the G7 bond returns. Furthermore, we had determined that they are stationary by the Kapetanios et al. (2003) nonlinear unit root test. In sum, it can be concluded that G7 government bond returns are stationary but possess a nonlinear feature. Our findings provide useful information for researchers interested in bond markets.

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I. Introduction

The bond market is a segment of the capital market of interest bearing securities and plays an important role in the world financial system. On one hand, the bond market facilitates the government implementing indirect instruments of monetary policy. Central banks in general, absorb and inject liquidity through the purchase and sale of government bonds. On the other hand, it helps the economy by improving the efficiency of overall economic management through expanding the range of opportunities to financing large scale projects. Besides, bond has been initially viewed by investors as a good substitute for stocks for balancing of portfolio of assets.

Due to its importance, many researchers have studied the bond market and its relationship with other financial markets. For example, since the seminal work by Markowitz (1952, 1959) which clearly addresses the importance of stock-bond correlation in constructing the optimal portfolio, many papers have been done to examine the co-movements between stock and bond markets. Some researchers provide empirical evidences on positive correlation among stocks and bonds (for example, Keim and Stambaugh (1986), Campbell and Ammer (1993), and Kwan (1996)). On the other hand, others find the correlations between bond and stock is negative (see, for instance, Gulko (2002), Connolly *et al*. (2005) and Baur and Lucey (2006)), while Alexander *et al*. (2000) find mixed sign correlations.

Besides the analyses of relationship between stock and bond markets, a few researchers also investigate the relationship among international bond markets. For example, Ilmanen (1995) uses a linear regression model with local and global instruments to forecast the excess returns of long-term international bonds. The world factors turn out to be the most important factors. Clare and Lekkos (2000) investigate the interaction between the US, UK, and German bond markets in a VAR model. Driessen et al. (2003) investigate the common factors in the US, German and Japanese bond markets using principal components analysis. They find that the positive correlation between bond markets is driven by the term structure levels (both world and local), not by the term structure slopes. Laopodis (2004) applies a VAR model to describe the long-term bond returns of eight countries. He finds that markets have become more integrated through the 1990s. Hunter and Simon (2005) investigate the relationships between the major world bond markets. Recently, Christiansen (2007) analyzes the volatility spillover from the US and aggregate European bond markets into individual European bond markets. She finds, for EMU countries, the US volatility spillover effects are rather weak whereas the European volatility-spillover effects are strong.

Interesting enough, though many researchers have investigated related issues on bond markets, there is no formal statistical test on the nonlinearity in the bond returns being studied. Recently, a large amount of evidence of nonlinearity has been found in many economic and financial time series.[1] In addition, various studies have demonstrated that

[1] For instance, there are reports of nonlinearity of the time series for exchange rates (Sarno, 2000; Baum *et al*., 2001; Liew, 2003; Liew *et al*., 2003; Lim *et al*, 2003; Baharumshah and Liew, 2006; Anoruo, 2006, among many others), interest rates (van Dijk and Franses, 2000; Shively, 2005; Baillie and Kilic, 2006), stock prices (Lim and Liew, 2004; Kanas, 2005; Lim and Liew, 2007), relative income (Liew and Lim, 2005; Chong *et al*., 2008), and others.

adopting linear methods will lead to incorrect statistical inference when the data are governed by nonlinearity; see, for example, Liew *et al*. (2003) and Liew *et al*. (2004), Kapetanios *et al*. (2003), and others. In particular, if the linear framework is found to be inadequate, the results of conventional linear unit root tests will then lose their power, and thus, any conclusion based on these tests could be misleading. As such, the robustness of the findings from the above-mentioned studies on the relationship among bonds, stocks and other macroeconomic factors is crucially hinged on the linearity property of the bond returns. Motivated by an enthusiasm to fill in the gap in the literature, we have conducted this study to determine the linear property and mean-reverting tendency of returns for various government bond indices in the G7 economies.[2]

The reminder of this study is organized as follows. Section II discusses the linearity test and various unit root tests under assumptions of both linearity and nonlinearity. This is followed by the description of the data being used in our study in Section III. Section IV presents our empirical results while concluding remarks are given in the final section.

II. Methodology

The mean-reverting tendency of a financial time series may be scrutinized by unit root tests. Briefly, if a series exhibits a stationary time series property, it is said to be mean-reverting. In this regard, the conventional Dickey-Fuller-type unit root tests (Dickey-Fuller, or DF, test, augmented Dickey-Fuller, or ADF, test, ADF test with GLS detrended series, or ADF-GLS) are popularly applied to check whether a series is stationary. Recently, the nonlinear version of Dickey-Fuller-type unit root tests from Kapetanios *et al*. (2003), the KSS test, is also available for the same purpose. There is evidence (Kapetanios *et al*., 2003, Liew *et al*., 2003, among others) showing that the linear Dickey-Fuller-type unit root tests have weaker power than their nonlinear counterparts in correctly identifying a stationary series if the series exhibits nonlinearity. In this respect, it is imperative to first determine the linear nature of the time series. A commonly used formal test for this purpose is the Luukkonen *et al*. (1988) linearity test.

Linearity test

In this study, we first adopt the following Luukkonen *et al*. (LST) (1988) test to examine whether the returns of bond indices being studied in this paper possess any nonlinear features:

$$y_t = \theta_0 + \left[\sum_{i=1}^{k} (\theta_{1i} y_{t-i} + \theta_{2i} y_{t-i} y_{t-d} + \theta_{3i} y_{t-i} y_{t-d}^2) \right] + \theta_4 y_{t-d}^3 + u_t \qquad (1)$$

[2] Among others, government bond returns use to be an important variable in the derivation of excess bond returns, using linear framework (Xu, 2007). This amounts to an implicit assumption of a linear relationship between excess bond return and government bond return. However, the resultant excess bond returns may be biased if government bond returns posses a nonlinear property.

where y_t = 100*ln(I_t/I_{t-1})% is the percentage log-difference return of a bond, in which I_t is the bond return index at time *t*, the parameters *k* and *d* are the optimal autoregressive order and the optimal delay lag length respectively,[3] and u_t is the stochastic error term.

In Equation (1), the null hypothesis is that y_t is a linear time series (that is, $\theta_{2i} = \theta_{3i} = \theta_4 = 0$, for all *i*'s), whereas the alternative hypothesis postulates that y_t is a nonlinear time series (that is, at least one θ is non-zero). The decision on whether y_t is linear can be made based on the *p*-value of the *F*-type test statistic of restriction. The decision rule is to reject the null hypothesis of linearity, and hence favoring the alternative hypothesis of nonlinearity, if the *p*-value or marginal significance value (*msv*) of the test statistic is less than a conventional significance level (Baum *et al*., 2001).

Nonlinear unit root tests

Recently, there has been empirical evidence (for example, van Dijk and Franses (2000), Sarno (2000), Baum *et al*. (2001), Kapetanios *et al*. (2003), Liew *et al*. (2003), Shively (2005), Baharumshah and Liew (2006), and Baillie and Kilic (2006)) that shows that financial time series are mostly nonlinear in nature. To cater for nonlinearity, Kapetanios *et al*. (2003) propose to first estimate the following nonlinear autoregressive process:[4]

$$\Delta y_t = \delta y_{t-1}^3 + \varepsilon_t ; \tag{2}$$

and

$$\Delta y_t = \delta y_{t-1}^3 + \sum_{j=1}^{p} \beta_j \Delta y_{t-j} + \varepsilon_t , \tag{3}$$

where y_t is the series of interest, and then check for the significance of δ. The null hypothesis of the nonstationary series ($\delta = 0$) is tested against the alternative hypothesis of the nonlinear stationary series ($\delta < 0$) based on the *t*-score of the estimated δ. The corresponding *t*-ratios of δ for these two specifications (Equations 2 and 3) of the nonlinear unit root test are denoted by t_{NDF} and t_{NADF}, respectively.

III. Data of Study

The data used in this study consist of the daily J.P. Morgan government bond return indices of G7 economies, namely, Canada (CN), France (FR), Germany (BD), Italy (IT), Japan (JP), the United Kingdom (UK), and the United States (US). All sample data are collected from *DataStream International* and denominated in US dollars. All sample data end at May 8, 2009, but the starting period varies across countries due to availability. For Canada, the United Kingdom and the United States, the samples start at

[3] Empirically, optimal autoregressive lag length (k) and delay lag length (*d*) can be determined from a range of integers such that the *p*-value of the *F*-type statistic is minimized.

[4] See Kapetanios *et al*. (2003) for details, or refer to Liew *et al*. (2004) for a brief overview.

January 1, 1985, whereas France, Germany and Japan start at January 1, 1986. As for Italy, the data start at October 1, 1993. In addition, daily bond returns of various maturity periods, including 1 to 3 years, 3 to 5 years, 5 to 7 years and 7 to 10 years, are analyzed in this study. The descriptive statistics for these daily returns are shown in Table 1.[5]

It is observed from Table 1 that means of daily bond returns for all the G7 countries are positive across all maturity periods, with the exception of 3- to 5-year bonds. The means of daily returns on the 1- to 3-year government bonds for Canada, France, Germany, Italy, Japan, the UK and the US are 0.0290%, 0.0349%, 0.0287%, 0.0253%, 0.0223%, 0.0332%, and 0.0238%, respectively.[6] Hence, the 1- to 3-year bonds of France appear to have generated the highest mean returns, while Japanese bonds register the lowest mean returns. The standard deviations of the 1- to 3-year bonds for the G7 countries are, in the same order, 0.4977%, 0.7029%, 0.7146%, 0.6371%, 0.7517%, 0.7094%, and 0.1428%, respectively. This suggests that among all of the G7 1- to 3-year bonds, France has the riskiest bonds, while US bonds carry the lowest risk. It is noted that French bonds are about 5 times riskier than those of the US, but the mean returns of the French bonds is only 1.5 times more than that of the US bonds. This implies that investors in US bonds are exposed to the least risk. On the other hand, based on the computed coefficients of variation, for the same unit of return, investors in Japanese bonds expose themselves to the highest risk among all of the 1- to 3-year bonds.

As for the 5- to 7-year bonds, the means of daily returns in descending order are 0.0375% (UK), 0.0371% (France), 0.0356% (Canada), 0.0337% (Germany), 0.0325% (Italy), 0.0309% (US.), and 0.0290% (Japan). The ranking of the countries according to the coefficients of variation (C.V.) in ascending order is US. (11.0680), Canada (16.3371), France (19.5013), UK (20.8427), Italy (22.3723), Germany (22.4510) and Japan (27.8517). This implies that an investor investing in Japanese bonds has to assume more than double the risk compared to an investor investing in the US bonds, for every percent of return obtained. The same ranking based on coefficients of variation is also observed for the 7- to 10-year bonds: US (13.2360), Canada (17.1057), France (19.6969), UK (21.5979), Italy (22.3255), Germany (23.8952), and Japan (27.4662). In sharp contrast to bonds of other maturity periods, negative daily mean returns are observed for the 3- to 5-year bonds for all of the G7 countries. The daily losses on these bonds range from 0.0262% (Japan) to 0.0353% (UK). Overall, we find that the US government bond market has the least risk for its investors and the market risk is substantially lower than others across all maturity periods, while the government bond market in Japan has the highest risk across all maturity periods.

[5] We follow the previous literature in applying log-returns of total return government bond indices, e.g., Bodart and Reding (1999) and Driessen *et al.* (2003).

[6] The figures amount to annual returns of 10.440%, 12.564%, 10.332%, 9.108%, 8.028%, 11.952% and 8.568% respectively for Canada, France, Germany, Italy, Japan, the UK and the US.

Table 1. Summary statistics of G7 government bond daily returns (percentage)

Country	Mean	Maximum	Minimum	Std. Dev.	C.V.	Skewness	Kurtosis
1- to 3-Year Bonds							
Canada	0.0290	5.1247	-6.5892	0.4977	17.1621	0.0539	28.6072
France	0.0349	9.5965	-6.2363	0.7029	20.1404	1.3274	21.4627
Germany	0.0287	8.4669	-7.2349	0.7146	24.8990	0.9490	22.2387
Italy	0.0253	4.6990	-3.8282	0.6371	25.1818	0.1490	6.1616
Japan	0.0223	9.2197	-6.9434	0.7517	33.7085	1.4858	23.9438
UK	0.0332	14.1896	-9.8005	0.7094	21.3675	2.5152	74.1355
US	0.0238	2.4061	-0.8780	0.1428	6.0000	5.9535	65.3833
3- to 5-Year Bonds							
Canada	-0.0326	7.3217	-5.8054	0.5466	-16.7669	-0.1040	30.9969
France	-0.0349	6.2363	-9.5965	0.7029	-20.1404	-1.3274	21.4627
Germany	-0.0317	8.0780	-9.2203	0.7410	-23.3754	-1.0127	24.1997
Italy	-0.0291	4.0348	-5.0229	0.6779	-23.2955	-0.0789	6.2061
Japan	-0.0262	7.3934	-14.0580	0.7801	-29.7748	-3.1459	50.5850
UK	-0.0353	8.7703	-14.7539	0.7441	-21.0793	-2.9992	74.1625
US	-0.0284	1.8045	-4.1082	0.2618	-9.2183	-3.1655	38.1521
5- to 7-Year Bonds							
Canada	0.0356	6.3992	-7.4944	0.5816	16.3371	0.4391	30.6475
France	0.0371	9.0181	-6.6573	0.7235	19.5013	1.1794	19.5255
Germany	0.0337	9.6106	-10.9450	0.7566	22.4510	1.4471	42.8345
Italy	0.0325	5.4109	-5.2446	0.7271	22.3723	-0.0384	6.9612
Japan	0.0290	10.3882	-7.5264	0.8077	27.8517	1.6159	28.1659
UK	0.0375	14.8221	-9.7563	0.7816	20.8427	3.1329	72.0263
US	0.0309	5.4906	-2.7599	0.3420	11.0680	2.7374	38.2193
7- to 10-Year Bonds							
Canada	0.0369	7.3727	-8.2992	0.6312	17.1057	0.4343	31.4119
France	0.0386	11.0350	-7.1564	0.7603	19.6969	1.4035	23.7978
Germany	0.0334	9.5403	-9.3058	0.7981	23.8952	1.0637	25.0468
Italy	0.0341	5.7164	-4.7598	0.7613	22.3255	-0.0009	6.2660
Japan	0.0311	10.4621	-8.9461	0.8542	27.4662	1.5817	31.1989
UK	0.0383	15.4013	-11.0311	0.8272	21.5979	3.0671	69.4442
US	0.0322	6.8407	-3.8412	0.4262	13.2360	2.5556	39.4075

Notes: We denote C.V. to be the coefficient of variation, which is the ratio of risk to return.

IV. Empirical Findings

We first adopt the Luukkonen *et al*. (1988) test to examine the nonlinear features of the returns of all the bonds and summarize the results in Table 2. From the *p*-values of the test statistics, which are all well below 0.05 with one exception, it is obvious that all of the bond returns across various maturity periods and countries exhibit a nonlinear nature, with the exception of the US 7- to 10-year bonds, for which the null hypothesis of linear returns can be rejected marginally at the 10% significance level (the corresponding *p*-value is 0.1026). This finding of nonlinear bond returns is in line with other recent studies that have found nonlinearities in financial market variables, such as interest rates (Baharumshah *et al*., 2008; Shively, 2005; Kapetanios *et al*., 2003; Bachmeier, 2002), exchange rates (Pérez-Rodríguez *et al*. 2009;Liew 2003; Liew *et al*., 2003; Liew *et al*. 2004; Taylor *et al*., 2001 and many others) and stock returns (Lim and Liew, 2007; Narayan, 2006; Shively, 2003). Thus, in determining the mean-reverting behavior of bond returns, one should avoid using the traditional linear stationary tests because these tests disregard the presence of nonlinearity and could yield deceptive conclusions.[7] Moreover, nonlinear framework deserves consideration in the construction of term spread using government bonds.[8]

Given that the underlying seven bond return series have a nonlinear nature and to circumvent the limitation of applying the traditional linear stationary test, we proceed to adopt the Kapetanios *et al*. (2003) nonlinear unit root test to investigate the mean-reverting property of the bond series[9, 10]. The results, which are reported in Table 3, for the 1- to 3-year G7 bonds, the *t*-statistics obtained from the nonlinearity stationary test are all smaller than the critical values at 1% significance level, implying the rejection of the null hypothesis of the non-stationarity of the nonlinear G7 bond return series. Similar findings are found for other maturity periods. Overall, it can be concluded that all the G7 bond returns are nonlinear stationary across various maturity periods.[11]

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[7] This finding also indicates that previous research results that used conventional linear models when examining the relationship between the bond market and other financial markets or modeling bond returns with simple autoregressive models should be interpreted with caution (see, for example, Ilmanen (1995), Clare and Lekkos (2000), Laopodis (2004), Christiansen (2007). In addition, if nonlinearity is present, it is likely that traditional unit root test may produce spurious results (see, for example Liew *et al.* (2003) and Liew *et al*. (2004), Kapetanios *et al.* (2003)).

[8] Previous studies regarded term spread as important linear predictor of excess bond returns (Jones and Roley, 1983; Shiller, Camplell and Shoenholtz, 1983; Campbell, 1986). Xu (2007), for instance obtained the term spread by subtracting 1-month Treasury bill rate from the 10-year government bonds.

[9] The optimal autoregressive lag, *p*, is selected from a range of integers from 1 to 12 inclusively. The one that minimizes the *t*-statistics is chosen (Baum *et al*, 2001). In financial time series, it is not uncommon to observed the same optimal autoregressive lag, k=1. Cheung and Lai (2001), for instance, have reported in their Tables 2 and 3 that k=1 for all 48 cases of the various different unit root tests they employed.

[10] As a preliminary analysis, the ADF-GLS test is estimated and the results are reported as Appendix. The results reveal that all bond returns are stationary by this test. Nonetheless, as the returns series are nonlinear, generating conclusion from the results of stationary tests that assume linear time series property like the ADF-GLS test here may be inappropriate.

[11] The authors would like to thank an anonymous reviewer for pointing out that for de-trended in the KSS test, there is a risk that the trend being removed is spurious under the null of a unit root. However, Kapetanios et al. (2003) stress that although finite sample power may be affected; the testing procedure is asymptotically similar with respect to intercepts or time trends. As such, KSS test should be robust with the use of daily data ranging from the shortest sample size of 3195 in the case of Italy, to more than 8500 observations for other countries.

Table 2. Linearity test results

Country	k	d	F	p-value
1- to 3-Year Bonds				
Canada	3	4	13.0631	0.0000
France	2	4	3.3993	0.0150
Germany	2	4	3.9079	0.0135
Italy	1	2	10.3306	0.0000
Japan	1	2	3.0763	0.0445
U.K.	1	3	4.2089	0.0415
U.S.A.	2	4	4.8700	0.0220
3 to 5 Years Bond				
Canada	1	4	8.4635	0.0000
France	2	4	3.3993	0.0075
Germany	1	2	4.9229	0.0020
Italy	1	2	8.2279	0.0000
Japan	3	2	3.2078	0.0055
UK	2	3	2.6747	0.0210
US	2	4	5.1890	0.0005
5- to 7-Year Bonds				
Canada	1	4	7.6438	0.0000
France	2	4	3.8203	0.0025
Germany	1	2	2.8970	0.0338
Italy	1	2	9.2161	0.0000
Japan	1	3	2.9372	0.0320
UK	1	5	3.5966	0.0130
US	2	4	4.4527	0.0010
7- to 10-Year Bonds				
Canada	3	4	5.7644	0.0000
France	2	4	3.1912	0.0120
Germany	2	4	4.7197	0.0005
Italy	3	2	4.3154	0.0000
Japan	4	3	2.5963	0.0325
UK	1	5	3.8585	0.0090
US	2	3	1.7555	0.1026

Notes: The F value is to test the null hypothesis of $\theta_{2i} = \theta_{3i} = \theta_4 = 0$, for all i's in Equation (1). Readers may refer to Luukkonen *et al*. (1988) for more information on the test statistics.

Table 3. Results of KSS test

Country	De-mean		De-mean and De-trend	
	p	*t*	*p*	*t*
1- to 3-Year Bonds				
Canada	1	-20.8463	1	-20.9991
France	1	-20.3692	1	-20.2784
Germany	1	-21.2201	1	-21.2249
Italy	1	-21.9378	1	-22.0318
Japan	1	-20.5992	1	-20.5047
UK	1	-26.1105	1	-26.1696
US	1	-26.1173	1	-26.2913
3- to 5-Year Bonds				
Canada	1	-19.6077	1	-19.5923
France	1	-16.0100	1	-16.0378
Germany	1	-18.0355	1	-18.0375
Italy	1	-18.3467	1	-18.3623
Japan	1	-19.1283	1	-19.1002
UK	1	-22.6307	1	-22.6532
US	1	-21.9463	1	-21.9516
5- to 7-Year Bonds				
Canada	1	-22.3300	1	-22.3090
France	1	-17.9416	1	-17.9709
Germany	1	-23.1075	1	-23.0969
Italy	1	-15.9877	1	-15.9793
Japan	1	-20.9119	1	-20.9719
UK	1	-24.0425	1	-24.0702
US	1	-21.2513	1	-21.2727
7- to 10-Year Bonds				
Canada	1	-22.0333	1	-22.0143
France	1	-16.3720	1	-16.3959
Germany	1	-18.5810	1	-18.5896
Italy	1	-17.6535	1	-17.6440
Japan	1	-21.8974	1	-21.9417
UK	1	-24.0301	1	-24.0551
US	1	-20.7291	1	-20.7519

Notes: The 1% null critical values for both KSS tests are -3.48 (de-mean) and -3.93 (de-mean and de-trend), respectively (Kapetanios *et al*., 2003).

V. Conclusions

Linearity and stationarity are two important and basic properties of a time series. This study applies the formal linearity tests introduced by Luukkonen *et al*. (1988) to examine the linear property of bond returns for the G7 economies. Our results reveal that all of the G7 bond returns are nonlinear in nature, which suggests that previous analysis results using linear approach such as linear regression model and linear VAR model should be interpreted with caution.[12] Further analyses based on the recently formulated nonlinear stationary KSS test (Kapetanios *et al*. 2003) show that all of the bond returns are exhibiting nonlinear mean-reverting behavior. Our results provide useful information for researchers interested in bond markets.

[12] This finding also provides a direction for further research of modeling bond returns using nonlinear models.

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Appendix: Results of ADF-GLS Test

Country	Level +Intercept		Level+Intercept and Trend	
	k	*t*	*k*	*t*
1- to 3-Year Bonds				
Canada	10	-24.781***	30	-10.194***
France	5	-32.615***	7	-26.578***
Germany	5	-32.668***	7	-26.299***
Italy	29	-4.584***	22	-8.580***
Japan	0	-77.189***	0	-77.204***
UK	0	-78.407***	0	-78.461***
US	23	-8.741***	23	-10.040***
3- to 5-Year Bonds				
Canada	8	-27.732***	30	-11.002***
France	5	-32.615***	7	-26.578***
Germany	5	-32.722***	7	-26.713***
Italy	29	-4.091***	29	-6.878***
Japan	0	-77.235***	0	-77.240***
UK	0	-78.574***	0	-78.634***
US	22	-12.195***	22	-13.043***
5- to 7-Year Bonds				
Canada	8	-27.383***	29	-11.845***
France	5	-32.638***	5	-32.259***
Germany	0	-78.060***	0	-78.002***
Italy	29	-4.236***	29	-7.050***
Japan	0	-76.656***	0	-76.599***
UK	21	-14.883***	21	-15.030***
US	22	-13.307***	22	-13.936***
7- to 10-Year Bonds				
Canada	5	-33.652***	7	-27.176***
France	5	-32.763***	5	-32.785***
Germany	5	-32.831***	5	-32.946***
Italy	29	-5.658***	18	-11.092***
Japan	0	-76.485***	0	-76.356***
UK	21	-14.852***	21	-14.908***
US	21	-14.353***	20	-15.324***

Notes: The optimal autoregressive lag order, *k* in the estimated model is selected based on AIC. *** indicates significant at 1% level.