Original Article

Persistence of volatility of sovereign credit risk in presence of structural breaks

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ABSTRACT The credit risk of a sovereign borrower is priced using bond spreads (BS) and credit default swaps (CDS). In this study, we investigate how structural breaks affect persistence of volatility of sovereign credit risk of seven countries. Using Kappa-1 and Kappa-2 tests, we identify multiple structural breaks in variance of both CDS and BS. Using exponential generalized autoregressive conditional heteroskedasticity model with and without structural breaks, we find that BS are more persistent than CDS hence informed trading takes place in sovereign bond market. The structural breaks are not only jointly significant in influencing volatility of sovereign credit but they reduce persistence of volatility and associated half-life of BS and CDS. The results have important implications on cost of

borrowing of sovereigns, efficiency of CDS and BS markets as well as pricing of both credit risk measures.

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INTRODUCTION

Credit default swaps (CDS) were introduced in 1997 by J.P. Morgan. Since then, CDS together with bond spreads (BS) have become the two most prevalent measures of credit or default risk of corporate and sovereign borrowers (reference entities). Duffie (1999) and Hull *et al* (2004) formalized the relationship between these two credit risk measures. If an investor is holding a zero-coupon par value bond with T -years to maturity and a yield to maturity equal to y , the BS is equal to y less risk free rate of US Treasury bond with equivalent T -years to maturity. The same bondholder¹ will buy protection or insurance against default by the bond issuer by paying the CDS premium or spread, usually expressed in basis points. The purchase of insurance makes the bond default risk free. Theoretically, CDS and BS should be equal at equilibrium. However, they are rarely equal, and it is not uncommon to encounter non-zero basis (CDS less BS) occasioned by market frictions (transaction costs, funding requirements for bonds, counter-party risks and restrictions on shorting bonds) in addition to features such as cheapest to deliver options embedded in CDS contracts. Nevertheless, CDS and BS still remain largely effective pointers of the credit risk of the same reference entity. The higher the credit risk, the higher the CDS and BS.

In this study, we focus on two important issues regarding sovereign BS and CDS of seven

emerging markets. First, which of the two instruments used to price credit risk exhibit higher persistence of volatility? Second, how do structural breaks affect this persistence of volatility?

The volatility of asset returns is important in the pricing of financial assets, predicting volatility, managing risk and asset allocation in a portfolio. As Ang *et al* (2006) argue, time-varying volatility either triggers changes in expected future returns or changes in risk–return trade-off. This will ultimately result in variation of investment opportunity set. This is important to policymakers trying to stabilize financial markets, investors trying to hedge risk, and fund managers seeking to rebalance their portfolios and hedge risk. For example, as the prices of sovereign bonds increase (bond yield and risk of default decreases), we would expect the prices of risk (measured by sovereign CDS) to decline. Conversely, as sovereign bonds held by hedge funds experience a dip in prices (yield and default risk increases), we would expect changes in CDS to increase to hedge against increased risk. We would thus expect an inverse relationship between percentage of bond return and changes in CDS. Figure 1² illustrates this point by showing the negative correlations between changes in sovereign CDS of six emerging markets and percentage of return of Eureka emerging markets' fixed income hedge fund index (HFI).

Figure 1: Source of Eureka emerging markets fixed income HFI.

Source: www.eurekahedge.com.

Ross (1989) shows that volatility of asset returns is directly related to the rate of information flow information to the market. As market participants use information to price the assets, the rate of information flow has important implications for efficient pricing of sovereign credit risk using BS and CDS, especially in the absence of arbitrage process. Therefore, volatility and its persistence form a solid foundation of testing efficient market hypothesis in BS and CDS.

As CDS and BS are intimately related and price credit risk of the same sovereign reference entity, we expect the prices and volatilities of the two securities to be linked in asset pricing models, an argument expounded by Fleming *et al* (1998). However, because of market frictions, especially in the bond market, the persistence of volatility of the two assets may differ. It is imperative to understand why persistence of volatility (not just volatility) is important. First, volatility of credit risk indicates uncertainty regarding the default risk of the borrower. As long as this uncertainty persists, the cost of sovereign borrowers will continue to rise. This may limit and prolong the borrower's ability to access capital markets to raise additional debt

to fund projects. Second, the persistence of volatility of asset prices also has implications regarding the degree of informed trading and information flow. Ross (1989) argues that in the absence of arbitrage opportunities, the volatility of stock price is equal to the volume of information flow, whereas the variance of stock return is proportional to variance of information flows. Further studies by Llorente *et al* (2002), Black (1986) and Kyle (1985) suggest that informed trading can be inferred from relative persistence of volatility in spot (bond) and derivative (CDS) markets. For example, if CDS returns³ exhibit higher persistence of volatility, this would confirm the theory that CDS markets are the principal locus of informed trading where informed investors trade on positive private information. Changes in price are likely to persist as the investors buy and drive up the price. Therefore, increase in amount of information available to traders in CDS market may produce information symmetry, which subsequently magnifies volatility of bond market.

Third, a counter view espoused by Attanasio (1990), Singleton (1987), and Grossman and Stiglitz (1980) argue that incomplete and asymmetric information in derivative market may

intensify persistence of volatility. The authors rationalize that in a market with asymmetric or imperfect information, uninformed traders will intensify their 'noise' and prevent prices from fully revealing private signals or information by informed traders. This will magnify volatility in the spot prices.

Fourth, Starica and Granger (2005) show that the variance of asset returns may experience sudden shifts, depending on the magnitude of news or information received in the market. This has an important implication on pricing of other assets. In fact, Belke and Gokus (2011) provide evidence of volatility spillovers among the CDS, bond and equity markets. Therefore, volatility in the CDS market may trigger persistent volatility and price changes in both equity and bond markets. This affects efficient pricing of government debt of any country that has important implications for diversification of risk by hedge fund managers⁴, lenders and policymakers striving to stabilize financial markets.

Volatility and its persistence can be best modeled using the generalized autoregressive conditional heteroskedasticity (GARCH) models some of which offer the advantage of capturing the leverage effects of Black (1976) and the mean reversion. However, these models are unable to capture sudden shifts in conditional volatility which, according to Lamoureux and Lastrapes (1990), Ewing and Malik (2005) and Cagli *et al* (2011) among others, could result not only in specious volatility modeling, but also overestimation of persistence parameters because of omission of variables, videlicet, structural breaks.

In this article, we contribute to existing literature by investigating persistence of volatility of sovereign credit risk and how structural breaks

affect this persistence. This is particularly important because past studies in this area have found that ignoring structural breaks in volatility modeling tends to overestimate persistence of volatility. Moreover, past studies on persistence of volatility have focused on stock markets of developed countries. To the best of our knowledge, this is one of the first papers to investigate the short-term dependence nature of volatility of instruments used to price sovereign credit risk in presence of structural breaks. The rest of the article is organized as follows: the next section details the sources and features of BS and CDS data; the section after that explains the econometric methodology utilized to gather evidence; the penultimate section discusses the empirical evidence while the final section summarizes and concludes.

DATA SOURCES AND CHARACTERISTICS

We gather daily, US dollar-denominated, standard 5-year sovereign CDS and emerging market BS. Specifically, for each of the seven sovereigns, we use Emerging Market Bond Index Global (EMBIG) sovereign BS from J.P. Morgan research and market database. The EMBIG spread is a market capitalization-weighted average of spreads on US dollar-denominated Brady bonds, Eurobonds and traded debt issued by sovereign and quasi-sovereign entities. Data from J.P. Morgan has been extensively used in academic research to price default risk sovereign US dollar-denominated public debt.

We use the standard 5-year BS since any variation in the maturities and types of bonds (sovereign and quasi-sovereign bonds) in the EMBIG could possibly distort the arbitrage relation between the BS and CDS. In some cases,

this could lead to negative or positive basis wrongly occasioned by varying maturities rather than arbitrage processes in the two markets. This also ensures that our results are not adulterated by the maturity structures of the data.

As of September 2011, the most heavily traded sovereigns CDS contracts (by gross national amount) were France, Italy, Germany and Spain. However, we focus on seven emerging markets as our sample for various reasons. First, France, Italy, Germany and Spain are all developed countries in European Union (EU) and became heavily traded just recently as most developed countries started experiencing financial problem during and 2007–2008 global financial crises. Their history is thus transient, and the historical data going back to pre-crisis period cannot truly and adequately capture the spirit of our study. As the International Monetary Fund (IMF) report indicates⁵, the importance of sovereign BS and CDS especially in developed economies has been growing rapidly since 2008. We therefore focus on seven emerging markets' sovereign or reference entities that have been consistently heavily traded (albeit some have toppled from top 10 from the onset of financial crisis).

Second, unlike developed countries in the EU, the emerging markets we study are highly susceptible to sudden structural breaks in volatility as they experience the destabilizing internal shocks from the social, economic and financial markets restructuring of political upheavals. These markets are also subject to external shocks emanating from financial markets of developed countries. We cannot gainsay the exigent need to incorporate structural breaks in estimation of volatility persistence coefficients for emerging markets as opposed to developed markets that have been largely stable in all aforementioned fronts.

Third, most post-crisis studies in sovereign BS and CDS have ignored emerging markets and focused almost entirely on EU. Therefore, we take a beeline in this study and focus on seven emerging markets, *videlicet*, Argentina, Brazil, China, Colombia, Mexico, Philippines and South Africa. The BS and CDS data for all sovereign nations have different starting dates but they have a mutual ending sample period ending date of 30 March 2012.

ECONOMETRIC METHODOLOGY

In this study, we use Kappa-1 (K1) and Kappa-2 (K2) tests of Sanso *et al* (2004). The two tests identify structural breaks in variance of time series. Both tests are nested in iterated cumulative sums of squares algorithm of Inclan and Tiao (IT henceforth, 1994), who developed the original structural break test called IT. We adopt the K1 and K2 tests for three main reasons. First, the Inclan and Tiao (IT) test is premised on the restrictive assumptions of homoskedasticity and mesokurtic (independent and Gaussian) distribution of disturbances in each regime identified. Andreou and Ghysels (2002) show that because of this inherent problem, the IT test tends to overestimate the number of structural breaks in variance. The K1 test corrects for this weakness especially the issue of kurtosis or fourth moment in distributions. The K2 corrects for dependence or persistence nature of volatility in presence of time-varying or conditionally heteroskedastic disturbances. Second, Rapach and Strauss (2008) find that the IT test is fraught with size distortions if serial correlations among the residuals, problem not prevalent in K1 and K2 tests. Third, the preliminary tests indicate that changes in CDS and BS are characterized by non-normal distributions (Jarque Bera (JB) test),

serial correlation of residuals (Breusch–Godfrey test (BG)), conditional heteroskedasticity (autoregressive conditional heteroskedasticity (ARCH) effects), and leptokurtic or fat-tail distribution. These features violate the conditions necessary for the application of IT test, hence we adopt the K1 and K2 tests.

To elaborate on K1 and K2 tests, we start with the original work of Inclan and Tiao (1994) who proposed to use the IT statistics to identify structural breaks in variance as follows:

First, IT developed D_k statistics to test the null of constant unconditional variance.

$$D_k = \frac{C_k}{C_T} - \frac{k}{T}, \quad k = 1, 2, \dots, T \quad (1)$$

where $C_k = \sum_{t=1}^k \varepsilon_t^2$ for $k = 1, \dots, T$ is the cumulative sum of squares of ε_t that is assumed to be $\varepsilon_t \sim iid N(0, \sigma^2)$ under the IT test. Then, $IT \Rightarrow \sup_r | \sqrt{T/2} D_k |$, where $\sqrt{T/2}$ standardizes the distribution. The asymptotic distribution of the test, annotated as IT, is given by

$$IT \Rightarrow \sup_r |W^*(r)| \quad (2)$$

According to Sanso *et al* (2004), $\Rightarrow$ represents weak convergence of probability measures associated with the test, $W(r)$ is the standard Brownian motion while $W^*(r) \equiv W_r - rW(1)$ is a Brownian bridge.

The Gaussian process advocated by IT test implies that kurtosis or fourth moment is equal to $\eta_4 = 3\sigma^4$. However, granted the fat-tail or leptokurtic distribution of returns, then $\eta_4 > 3\sigma^4$ which will generate higher frequency of rejecting the null hypothesis of homoskedasticity. Sanso *et al* (2004) adjusted the IT test to remove the nuisance parameter of *iid* residuals. The

developed K1 test as follows:

$$k_1 = \sup_k |T^{-1/2} B_k| \quad (3)$$

$$B_k = \frac{C_k - \frac{k}{T} C_T}{\sqrt{\hat{n}_4 - \hat{\sigma}^4}} \quad (4)$$

and $\hat{n}_4 = T^{-1} \sum_{t=1}^T \varepsilon_t^4$, $\hat{\sigma}^2 = T^{-1} C_T$ for $k \in \{1, 2, \dots, T\}$

The asymptotic distribution of the K1 test is premised on the idea that if $\varepsilon_t \sim iid$ and $E(S_t^4) \equiv \eta_4 < \infty$, then, $K1 \Rightarrow \sup_r |W^*(r)|$

To overcome the assumption of independence of returns in data-generating process inherent in both IT and K2 but still incorporate heteroskedasticity, Sanso *et al* (2004) assumed, under some conditions⁶ that the sample data can be viewed as a sequence of random variables, $\{\varepsilon_t\}_{t=1}^\infty$. This led to development of K2 test, where

$$k_2 = \sup_k |T^{-1/2} G_k| \quad (5)$$

$$G_k = \hat{\omega}_4^{-1/2} \left(C_k - \frac{k}{T} C_T \right)$$

$\hat{\omega}_4$ is a consistent estimator of ω_4 , and ω_4 can be estimated non-parametrically as follows⁷:

$$\hat{\omega}_4 = \frac{1}{T} \sum_{t=1}^T (\varepsilon_t^2 - \hat{\sigma}^2)^2 + \frac{2}{T} \sum_{l=1}^m \omega(l, m) \sum_{t=l+1}^T (\varepsilon_t^2 - \hat{\sigma}^2) (\varepsilon_{t-l}^2 - \hat{\sigma}^2) \quad (6)$$

where $\omega(l, m) = 1 - (l/(m+1))$. In addition, if $\xi_t = \varepsilon_t^2 - \hat{\sigma}^2$, then $\hat{\omega}_4 \rightarrow E(\xi^2) = \eta_4 - \sigma^4$

According to Cumby *et al* (1993) and Cheng *et al* (2001), exponential generalized autoregressive conditional heteroskedasticity (EGARCH) offers three main advantages relative to GARCH model. First, EGARCH model does not require ARCH and GARCH coefficient estimates to be restricted to positivity. Second, EGARCH

formulation captures both the sign and size of the past shocks affecting contemporaneous variance of returns. Finally, EGARCH models standardized residuals as a moving average that is able to capture the asymmetry of positive and negative news or shocks (leverage effects) that characterize most stationary time series. According to Black (1976), the leverage effects capture the tendency of negative news to magnify conditional volatility more than good news of the same magnitude. The EGARCH model of Nelson (1991) is as follows:

$$\ln \sigma_t^2 = \varpi + \alpha \left| \frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}} \right| + \gamma \frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}} + \beta \ln \sigma_{t-1}^2 \quad (7)$$

In equation (7), ϖ is unconditional volatility, α coefficient captures the size effect of a standardized previous shock ($|\varepsilon_{t-1}|$), whereas γ captures the leverage effects. β coefficient estimates indicate persistence of conditional volatility, σ^2 . The coefficients α and γ should be positive and negative, respectively, while the closer β is to unity, the higher the persistence of volatility. Lamoureux and Lastrapes (1990) states that conventional EGARCH models tend to overestimate persistence of volatility if structural breaks in variance are not accounted for. Therefore, to get more reliable estimates for the persistence of uncertainty of default risk of sovereign borrowers, we add structural breaks to our univariate EGARCH model as follows:

$$\ln \sigma_t^2 = \varpi + \alpha \left| \frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}} \right| + \gamma \frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}} + \beta \ln \sigma_{t-1}^2 + \sum_{i=1}^n \text{dnDUM}_n \quad (8)$$

DUM_n is a set of dummy variables that takes a value of 1 from the structural break date onward

and 0 otherwise. To estimate the model parameters, we maximize the log-likelihood using the Berndt *et al* (1974) algorithm. We also use generalized error distribution to capture fat-tail distribution of CDS and BS returns.

EMPIRICAL EVIDENCE

The descriptive statistics in Table 1 capture the main features of the sovereign CDS and BS returns. The returns of all credit risk measures except China and South Africa's CDS returns and Philippines and South Africa's BS returns indicate positive skew. With exception of the Argentina's BS returns, the BS and CDS returns have positive excess kurtosis (kurtosis greater than 3) thus exhibit leptokurtic or fat-tail distributions.

Although the skew is relatively small, the positive (negative) skew implies that trading on both CDS and BS generates higher probability of positive (negative) returns. The Jacque and Bera (JB) (1987) test whose null is normal distribution or asset returns, is decisively rejected indicating non-normal distribution of CDS and BS returns. Given the relatively small skewness, we can conclude that non-normality is largely driven by leptokurtosis. The ARCH test of Engle (1982), which have a null of constant variance (homoskedasticity) rejects the null at 16 lags. The Breusch (1979) and Godfrey (1978) tests (BG (16) of serial autocorrelation or dependence up to 16 lags of residuals (the null is zero autocorrelation) strongly reject the null at 1 per cent significance level. The existence of heteroskedasticity, non-normality, fat-tails and autocorrelation of residuals justify adoption of EGARCH modeling. These features are also inherent in returns of other securities especially stocks.

Table 1: Descriptive statistics, ARCH and serial autocorrelation tests

<i>Country</i>	<i>Mean</i>	<i>Q1</i>	<i>Q3</i>	<i>Standard deviation</i>	<i>skew</i>	<i>kurtosis</i>	<i>JB-test</i>	<i>n</i>	<i>ARCH(16)</i>	<i>BG(16)</i>
<i>Argentina</i>										
BS	0.00032	-0.006	0.0072	0.0233	1.131	1.451	***552.07	1762	***4.701	***6.581
CDS	0.00046	-0.016	0.0152	0.0325	0.633	6.285	***909.91	1762	***7.531	***15.824
<i>Brazil</i>										
BS	-0.0007	-0.012	0.0098	0.0264	0.704	8.341	***3468.74	2729	***35.261	***5.862
CDS	-0.0008	-0.021	0.0179	0.0411	0.375	10.838	***7049.28	2729	***20.617	***4.635
<i>China</i>										
BS	0.00048	-0.002	0.0033	0.0153	2.338	127.017	***1538292.96	2397	0.100	***39.726
CDS	0.00001	-0.028	0.0279	0.0642	-0.31	10.788	***6096.51	2397	***3.355	***2.890
<i>Columbia</i>										
BS	-0.0007	-0.011	0.0101	0.0313	0.601	31.661	***82185.40	2397	***35.199	***3.687
CDS	-0.0008	-0.019	0.0147	0.0398	0.368	12.129	***8377.96	2397	***14.976	***6.386
<i>Mexico</i>										
BS	-0.0003	-0.011	0.0118	0.0280	0.200	7.195	***2020.29	2730	***41.568	***3.189
CDS	-0.0003	-0.022	0.0202	0.0474	0.495	20.162	***33612.83	2730	***16.933	***3.423
<i>Philippines</i>										
BS	-0.0005	-0.002	0.0095	0.0253	-0.14	27.573	***60920.65	2421	***67.616	***10.307
CDS	-0.0005	-0.016	0.0142	0.0352	0.184	10.877	***6273.17	2421	***52.404	***4.353
<i>South Africa</i>										
BS	-0.0001	-0.016	0.0217	0.0435	-0.29	3.282	***45.82	2588	***15.145	***9.992
CDS	0.00003	-0.023	0.0232	0.0690	-0.19	93.115	***875693.95	2588	***5.244	***10.855

*** represents statistical significance at 1 per cent significance level.

Notes: Q1 and Q3 are first and third quartiles mean return. JB is the Jacque–Bera test of normal distribution of returns while *n* is the number of observations. ARCH (16) is the Autoregressive conditional heteroskedasticity test of Engle (1982) up to 16 lags while BG (16) is the Breusch—Godfrey serial autocorrelation test of Godfrey (1978) and Breusch (1979) up to 16 lags.

We then test for unit root or non-stationary features of CDS and BS at levels. We use the more efficient Dickey–Fuller Generalized Least Squares (DG-GLS) test of Elliott *et al* (1996) which tests the null of unit root against the alternative of stationary. We also use unit root test of Kwiatkowski *et al* (1992) test based on the null hypothesis stationary against non-stationary. Finally, we use Zivot and Andrews’ (1992) test which has a null hypothesis of unit root test excluding exogenous structural breaks at the intercept (*du*) and at intercept and trend (*du* and *dt*), respectively. The results are presented in Table 2. The Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test rejects stationarity in all cases and thus confirms unit root. The DF-GLS rejects unit root for Brazil’s BS and South Africa’s BS and CDS. Using Zivot and Andrews (ZA) test⁸, we reject the null for Brazil’s BS and CDS, and China and Argentina’s BS. For the remaining CDS and BS returns, we fail to reject unit root excluding structural break at the intercept and at the intercept and trend. In sum, we find that BS and CDS at levels have a unit root using at least one of the three tests. Therefore, we use the log of first difference (CDS and BS returns) for subsequent analysis. Having confirmed that CDS and BS at levels are integrated of order one [*I*(1)] at levels, we compute the log of first difference to make the data stationary. The results of stationarity test are not presented to conserve space. We denote the first difference as BS and CDS returns. We use the returns, and the Sanso *et al*’s (2004) tests to endogenously identify structural breaks in volatility.

Therefore, there is no potential for data mining in testing for breaks in volatility. The K1 and K2 tests correct for serial interdependence, heteroskedasticity and non-normal distribution of returns. These features characterize the BS and

Table 2: Unit root tests using level time series data

Country	DFGLS1	DFGLS2	KPSS1	KPSS2	ZA1	t-stat1	Tb1	ZA2	t-stat2	Tb2
<i>Argentina</i>										
BS	-1.663	-2.146	***1.419	***0.513	**−4.92	-2.82	1001	-2.31	-2.72	800
CDS	-1.744	-2.077	***0.968	***0.562	-2.97	-2.66	1039	-3.14	-3.74	843
<i>Brazil</i>										
BS	-0.260	-1.878	***3.634	***0.768	***−9.1	-4.26	261	***7.26	-7.24	261
CDS	-1.333	*−2.578	***2.946	***0.606	***−12.1	-4.28	301	***−9.6	-8.63	262
<i>China</i>										
BS	-0.485	-1.662	***2.735	***0.268	**−4.90	-2.48	2202	4.16	-3.87	1615
CDS	-1.909	-1.942	***2.217	***0.322	3.148	-4.61	1290	-2.36	-4.83	1468

<i>Colombia</i>										
BS	0.028	−1.527	***2.441	***0.549	3.298	−4.41	1396	−1.18	−4.34	1406
CDS	0.325	−1.062	***3.256	***0.843	3.192	−4.74	1401	2.95	−4.50	1162
<i>Mexico</i>										
BS	−0.599	−1.703	***0.845	***0.690	3.802	−4.53	1742	−1.49	−4.61	1742
CDS	−0.854	−1.759	***0.769	***0.701	3.223	−4.33	1730	−1.16	−4.33	1768
<i>Philippines</i>										
BS	−0.159	−2.052	***2.802	***0.437	3.468	−4.64	1428	−0.82	−4.64	1428
CDS	−0.216	−2.079	***3.454	***0.619	3.528	−4.77	1393	2.16	−5.19	1303
<i>South Africa</i>										
BS	***−2.568	*−2.688	***0.953	***0.428	2.578	−3.26	1436	−1.22	−3.28	1436
CDS	***−2.656	*−2.691	***1.046	***0.542	3.405	−4.44	1468	−0.04	−4.37	1468
<i>Critical Values</i>										
1%	−2.566	−3.480	0.739	0.216	−5.34	—	—	−5.57	—	—
5%	−1.941	−2.890	0.463	0.146	−4.80	—	—	−5.08	—	—
10%	−1.617	−2.570	0.347	0.119	−4.58	—	—	−4.80	—	—

*, ** and *** shows statistical significance at 10 per cent, 5 per cent and 1 per cent significance levels, respectively.

Notes: DFGLS1 (DFGLS2) is the Dickey—Fuller Generalized Least Squares test of Elliot *et al* (1996) with intercept (intercept and trend). KPSS1 (KPSS2) is Kwiatkowski, Phillips, Schmidt and Shin's (1992) test with intercept (intercept and trend). ZA1 and ZA2 is the ZA (1992) unit root test with structural break at the intercept (*du*) and intercept and trend (*du* and *dt*), respectively. *t*-stat1 and *t*-stat2 is the standard *t*-statistics testing for unit root test with *du* and *du* and *dt* structural break tests.. Tb1 and Tb2 are the structural break dates when testing for structural break at the intercept (*du*) and intercept and trend (both *du* and *dt*), respectively.

Table 3: Structural break dates of variance using K1 and K2 tests

Country	$T_B(k1)$			N_B	$T_B(k2)$			N_B
Argentina								
BS	11 June 2007	22 October 2008	1 January 2009	—	11 June 2007	1 January 2009	—	—
—	11 December 2007	12 September 2008	—	5	—	—	—	2
CDS	3 October 2005	6 June 2007	—	—	11 June 2007	1 January 2009	—	—
—	29 June 2006	29 June 2009	—	4	—	—	—	2
Brazil								
BS	5 December 2001	8 August 2003	24 March 2008	—	3 June 2002	7 November 2002	8 August 2003	—
—	3 June 2002	27 January 2004	12 September 2008	—	28 June 2002	1 May 2003	27 January 2004	—
—	28 June 2002	17 June 2004	31 October 2008	—	—	—	—	—
—	7 November 2002	12 June 2007	1 January 2009	—	—	—	—	—
	1 May 2003	—	—	13	—	—	—	6
CDS	19 July 2007	29 October 2008	25 May 2011	—	18 September 2007	17 December 2008	—	—
—	18 September 2007	17 December 2008	11 November 2011	—	12 September 2008	4 June 2010	—	—
—	12 September 2008	4 June 2010	5 March 2012	9	29 October 2008	25 May 2011	—	6
China								
BS	30 April 2009	4 June 2010	—	2	17 July 2007	23 May 2011	—	—
CDS	30 April 2009	4 June 2010	—	2	30 April 2009	4 June 2010	—	4
Colombia								
BS	14 April 2004	11 June 2007	12 September 2008	—	7 June 2004	19 September 2007	22 October 2008	—
—	7 June 2004	17 August 2007	22 October 2008	—	10 March 2005	26 June 2008	1 December 2008	—
—	10 March 2005	26 June 2008	1 December 2008	—	11 June 2007	12 September 2008	—	8
—	7 February 2006	—	—	10	—	—	—	—
CDS	31 August 2004	30 August 2008	3 August 2011	—	7 June 2004	27 September 2007	22 October 2008	—
—	3 January 2005	17 December 2008	14 December 2011	—	10 March 2005	26 June 2008	1 December 2008	—
—	31 January 2006	1 February 2011	28 February 2012	—	11 June 2007	12 September 2008	—	—
—	12 September 2008	—	—	10	—	—	—	8

Mexico

BS	31 May 2007	12 September 2008	31 December 2008	—	31 May 2007	12 September 2008	31 December 2008	—
—	24 March 2008	30 October 2008	—	5	24 March 2008	30 October 2008	—	5
CDS	4 January 2002	19 July 2007	12 September 2008	—	31 May 2007	12 September 2008	31 December 2008	—
—	25 March 2004	19 September 2007	23 October 2008	—	24 March 2008	30 October 2008	—	—
—	5 January 2005	18 April 2008	18 December 2008	—	—	—	—	—
—	6 July 2006	—	—	10	—	—	—	5

Philippines

BS	20 May 2004	12 May 2006	11 September 2008	—	20 May 2004	12 May 2006	11 September 2008	—
—	4 March 2005	1 December 2006	2 December 2008	6	4 March 2005	1 December 2006	2 December 2008	6
CDS	13 December 2005	17 January 2008	26 November 2008	—	13 December 2005	17 January 2008	26 November 2008	—
—	13 July 2007	22 September 2008	25 November 2010	—	8 June 2007	2 September 2008	—	—
—	15 August 2007	24 October 2008	22 July 2011	9	—	—	—	5

South Africa

BS	1 May 2003	17 August 2007	12 September 2008	—	1 May 2003	17 August 2007	12 September 2008	—
—	12 December 2006	5 February 2008	1 January 2009	6	12 December 2006	5 February 2008	1 January 2009	6
CDS	23 March 2004	4 January 2005	30 October 2008	—	1 May 2003	17 August 2007	12 September 2008	—
—	—	—	—	3	12 December 2006	5 February 2008	1 January 2009	6

Notes: T_B (K1) and T_B (K2) are structural break dates or points for BS and CDS variance dates using K1 and K2 tests. N_B is the number of structural breaks.

Table 4: Persistence of variance without structural breaks

Country	α	γ	β	ARCH(16)	Half-life
<i>Argentina</i>					
BS	***0.1802	−0.0054	***0.9976	0.199	288.5
CDS	***0.3119	***−0.0836	***0.8991	1.001	6.5
<i>Brazil</i>					
BS	***0.2126	***−0.0291	***0.9907	0.227	74.2
CDS	***0.2154	***−0.0433	***0.9593	1.588	16.7
<i>China</i>					
BS	***0.1960	*−0.0134	***0.9729	0.684	25.2
CDS	***0.4581	***−0.1030	***0.8202	0.249	3.5
<i>Columbia</i>					
BS	***0.2096	*−0.0214	***0.9863	0.012	50.2
CDS	***0.3541	***−0.0534	***0.9527	0.728	14.3
<i>Mexico</i>					
BS	***0.2167	**−0.0233	***0.9918	0.385	84.2
CDS	***0.1972	***−0.0570	***0.9604	0.238	17.2
<i>Philippines</i>					
BS	***0.2556	*−0.0268	***0.9722	1.028	24.6
CDS	***0.2862	*−0.0297	***0.9672	0.461	20.8
<i>South Africa</i>					
BS	***0.1630	−0.0051	***0.9959	1.047	168.7
CDS	***0.3327	***−0.0629	***0.9244	0.544	8.8

*, ** and *** shows statistical significance at 10 per cent, 5 per cent and 1 per cent significance levels, respectively.

Notes: ARCH (16) is the Engle (1982) test with the null of constant variance (homoskedasticity) of residuals.

CDS returns. We report in Table 3 the results of structural break tests. First, we find multiple structural breaks in variance of CDS and BS. Second, the break points or dates vary across sovereigns. Third, majority of breaks seem to have occurred around the 2007/2008 global financial crisis as most of the structural break dates fall in either 2008 or 2009.

This is a confirmation that a global event such as a global financial crisis emanating from developed countries such as the United States can trigger a fundamental shift in variance or uncertainty of sovereign credit risks.

Having identified the structural breaks in volatility of BS and CDS, we then test how the breaks affect persistence of volatility of sovereign credit risk. However, to assess the impact of the breaks on persistence of volatility, we first run a base EGARCH model without incorporating structural breaks. Table 4 presents the estimates of α coefficient (effects of size of shock on conditional volatility), γ (leverage effect) and β (persistence of volatility). We find interesting results.

First, volatility of both BS and CDS returns is highly persistent with all sovereigns recording

a persistence of 0.90 or higher except China's CDS. This evidence is captured by β coefficient estimates. The high degree of persistence of uncertainty of sovereign credit risk implies shocks to conditional volatility will dwindle slowly over time. Therefore, sovereigns are likely to pay high cost of borrowing as long as this uncertainty persists. This could also constrain the sovereign borrower from accessing new credit from lenders until volatility or uncertainty peters out. This may exacerbate liquidity problem of the borrower. A classic case in point is Greece where sovereign CDS have been consistently high as uncertainties regarding burgeoning budget deficits and potential default have persisted for almost the past 2 years.

One notable finding is that the persistence parameter for BS is consistently higher than that of CDS for all the sovereigns in which case the sovereign bond market is the vehicle of price leadership in price discovery process. Using Ross's (1989) argument, this could suggest that informed trading occurs in the sovereign bond market. A counter argument by Attanasio (1990), Singleton (1987) and Grossman and Stiglitz (1980) states that it can also be argued that the asymmetric or imperfect information in bond market will enhance trading by uninformed traders who will intensify their 'noise' and prevent true prices of credit risk from being fully revealed by private signals or information from informed traders in the CDS market. This will magnify volatility in the bond prices and increase persistence of such volatility. In this model, persistence of volatility is caused by uninformed trading⁹.

Second, the half-life, which according to Lamoureux and Lastrapes (1990) shows the number of periods (days) a shock to conditional variance takes to shrink to half its initial size varies

across the sovereigns. For example, shocks to conditional variance of Argentina's BS will take 288 days (more than 1 year trading days) to revert to original size, whereas a shock to conditional variance of China's CDS returns will take only 3.5 days to shrink to original size. The shorter the half-life, the faster the uncertainty dissipates.

Third, the asymmetry or leverage effect coefficients (γ) is significant and negative for all sovereigns. This implies that bad news or negative shocks intensify or have destabilizing effects on conditional volatility of both BS and CDS more than positive shocks (good news) of equal magnitude. Finally, we find that in all cases, coefficient of persistence, β is greater than α . This suggests that large shocks to the market do not trigger significant revisions in future conditional volatility. Satisfying this condition, together with the fact that almost all the coefficient estimates are statistically significant, indicates the EGARCH model is stationary.

The EGARCH model with (without) structural breaks may be considered as unrestricted (restricted), hence both models are nested in each other. In Table 5, we summarize the results of EGARCH model which account for structural break. The results are based on breaks identified by K1 and K2 tests. To preserve space and without loss of information, we report the leverage effect coefficient γ and persistence of volatility coefficient, β . We document interesting evidence. First, in Argentina and South Africa, CDS returns exhibit higher persistence of volatility than BS, a reversal of evidence without structural breaks. In these two countries, CDS market may be dominated by informed traders. The persistence of volatility of BS remains higher than that of CDS in the remaining sovereigns. Second, with exception of China's CDS, the persistence of volatility register significant

Table 5: Persistence of volatility in presence of Structural breaks

Country	Security	γ	β	Percentage of change	half- life	$F\text{-(DUM)}$	LR	ARCH (16)
<i>Panel A: Using k1 breaks</i>								
Argentina	BS	−0.043	***0.602	−39.61	1.37	***6.316	***72.33	0.509
	CDS	−0.083	***0.869	−3.32	4.94	1.357	***7.57	0.917
Brazil	BS	***−0.053	***0.926	−6.57	9.02	***3.461	***117.5	0.126
	CDS	***−0.057	***0.872	−9.06	5.06	***3.839	***45.82	0.132
China	BS	−0.007	***0.928	−4.60	9.28	***21.905	***43.84	0.908
	CDS	−0.114	***0.834	+1.74	3.82	***12.152	***97.88	0.172
Colombia	BS	0.010	***0.955	−3.13	15.05	***7.340	***128.40	0.147
	CDS	***−0.071	***0.819	−14.03	3.47	***3.170	***69.07	1.329
Mexico	BS	***−0.037	***0.917	−7.57	8.00	***7.659	***111.60	0.315
	CDS	**−0.049	***0.783	−18.51	2.83	**2.922	***40.87	0.138
Philippines	BS	−0.019	***0.912	−6.16	7.53	***4.234	***126.9	0.532
	CDS	**−0.045	***0.874	−9.60	5.15	***2.438	***50.71	1.757
South Africa	BS	**−0.053	***0.647	−35.00	1.59	***3.148	***131.40	0.301
	CDS	***−0.050	***0.730	−21.03	2.20	***212.625	***569.50	0.692
<i>Panel B: Using k2 breaks</i>								
Argentina	BS	−0.036	***0.803	−19.55	3.16	***11.689	***63.09	0.514
	CDS	−0.079	***0.883	−1.77	5.57	1.000	***3.31	0.997
Brazil	BS	***−0.052	***0.920	−7.15	8.31	***8.034	***112.80	0.111
	CDS	***−0.045	***0.927	−3.40	9.14	**2.646	***20.60	1.473
China	BS	−0.007	***0.928	−4.60	9.28	***21.905	***43.84	0.908
	CDS	***−0.075	***0.855	+4.23	4.43	***3.235	***−57.12	0.214
Colombia	BS	−0.01	***0.964	−2.24	18.91	***10.794	***118.8	0.086
	CDS	**−0.051	***0.923	−3.13	8.65	**1.989	***20.36	0.567
Mexico	BS	***−0.055	***0.826	−16.69	3.63	***4.740	***108.9	0.279
	CDS	***−0.042	***0.925	−3.69	8.89	**2.367	***14.57	0.245
Philippines	BS	−0.019	***0.912	−6.16	7.53	***4.234	***126.90	0.532
	CDS	−0.028	***0.914	−5.45	7.71	***3.476	***29.62	0.32
South Africa	BS	**−0.053	***0.647	−35.00	1.59	***3.148	***131.40	0.301
	CDS	**−0.035	***0.272	−70.53	0.53	***32.238	***422.80	1.643

*, ** and *** shows statistical significance at 10 per cent, 5 per cent and 1 per cent significance levels, respectively.

Notes: LR is the likelihood ratios computed as $2[L(\Phi_b) - L(\Phi_0)]$, where $L(\Phi_b)$ and $L(\Phi_0)$ are the log-likelihoods for EGARCH models with and without structural breaks in variance. $F(\text{DUM})$ is the F -statistics for the joint test of joint significance of the dummy variables (DUM). Percentage of change represents the percentage of change in persistence with and without the breaks. The half-life for EGARCH model is computed as $-\ln(2)/\ln(\beta)$. ARCH (16) is Engle's (1982) ARCH-LM test up to 16 lags.

declines after accounting for structural breaks, suggesting that ignoring structural breaks in volatility tends to overestimate persistence parameter, β . Moreover, the half-life also declined by significant percentages hence in presence of structural breaks, shocks to conditional volatility take lesser days to revert to half of original size. Third, to test the fit of the model, we compute the likelihood ratio (LR) to test the null hypothesis that the unrestricted EGARCH model (with breaks) does not fit the data significantly better than restricted EGARCH model (without breaks). The LR is computed from the log likelihood estimates of the two models. The LR is strongly significant, evidence that the EGARCH model with breaks (using dummies) fits significantly better than restricted EGARCH model without breaks.

We also conduct Wald F -statistics test to investigate whether inclusion of the dummies significantly improves the fit of the model. Specifically, we test the null that all dummy coefficients are simultaneously equal to 0 ($H_0: dn1 = dn2 = \dots = dnn = 0$, where dn are dummies 1 ... n coefficient estimates). We decisively reject the null using F -statistics (F -DUM) suggesting that including dummies to proxy for structural breaks significantly improves our results. The ARCH test up to 16 lags indicates that the residuals are homoskedastic. In sum, ignoring breaks caused by fundamental shifts in volatility may yield incorrect results and inference therefrom.

SUMMARY AND CONCLUSION

In this study, we investigate persistence of volatility of sovereign credit risk and how multiple structural breaks in volatility affect

volatility persistence. This is one of the first studies to investigate the volatility dependence behavior of sovereign BS and CDS. We find that BS and CDS returns are characterized by skewness, fat-tail distributions, heteroskedasticity and serial correlation of residuals. Unlike past studies in other asset returns that use IT test, we use K1 and K2 tests and endogenously identify multiple structural breaks. These two tests correct for dependence of assets returns, heteroskedasticity and non-normal distribution of returns features that were found in BS and CDS returns. Using EGARCH model without breaks, we find that BS have higher persistence of volatility than CDS. We also find not only multiple structural breaks, but also that these structural breaks significantly reduce persistence of volatility of sovereign credit risk and corresponding half-life. Therefore, failure to account for structural breaks in volatility tends to overestimate persistence and half-life and may yield incorrect inferences for policy purposes. Moreover, BS generally seems to have higher persistence of volatility before and after accounting for structural breaks. This may suggest that either informed trading takes place in the bond market or presence of asymmetric information and noise trading in the bond markets. Our findings have important implications on cost of borrowing by sovereigns, pricing of sovereign credit risk, and the efficiency of CDS and BS markets. The fact that volatility persists and is predictable suggests that future changes in BS and CDS prices can be predicted from current price changes. This is a violation of efficient market hypothesis. Hedge fund managers, arbitrageurs and speculators can also use the results to formulate pairs trading strategies and engaging in arbitrage process.

NOTES

- 1 In naked CDS, speculators, who are not bondholders, pay CDS premium to speculate that the reference entity is going to default. This misuse of CDS was one of the major triggers of 2007/2008 financial meltdown.
- 2 HFI is the monthly percentage of return of Eureka emerging market fixed income hedge fund index. BRA, ARG, COL, MEX, PHN and SAF are the monthly percentage of return of sovereign CDS for Brazil, Argentina, Colombia, Mexico, Philippines and South Africa.
- 3 In this study, we use stationary data. Therefore, we use log of first difference of level BS and CDS that we consistently refer to BS and CDS returns, respectively.
- 4 See Figure 1.
- 5 'A new look at the role of sovereign credit default swaps', Financial Stability Report, April 2013, IMF.
- 6 See Sanso *et al* (2004) for more information.
- 7 In derivation of K1 and K2, the bandwidth selection is based on Newey–West methodology.
- 8 In ZA test, we report the higher of the two ZA values: The one generated by ZA test on intercept only and the one generated by ZA test of structural break in intercept and trend.
- 9 In this study, we are not testing for the appropriate theory that can explain persistence of volatility but we attempt to offer competing theories that can explain our results.

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