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# Global Shock and Regional Spillovers

**Abstract:** When global crisis struck at a time of great global and regional interdependence, contagion occurs; it can work via capital flows or through spillovers of the returns/yields on financial assets. The analysis in the paper deals with the latter. Focusing on the shocks in the United States and Eurozone bonds market, and using multivariate GARCH models with conditional variance-covariance matrix being positive definite, it is shown that the shock and volatility spillovers in some emerging Asian countries are quite significant. They spread throughout different asset classes, threatening the region's financial stability, and making it more difficult for the policy response to focus on a particular market. Although local bonds volatilities are more determined by their own respective shocks and volatilities, in some markets the direct shock and volatility spillovers remain significant; so does the indirect spillovers within domestic asset markets and across economies. Absent of policy coordination within and across countries. Such undesirable spillovers due to other country's unilateral policy can be damaging. Growing financial nationalism in the midst of a crisis is likely to spark strong reactions from affected countries, potentially creating a conflict situation.

**Keywords:** spillovers, contagion, sovereign bond yields and returns, conditional volatility, emerging East Asia local currency bond markets, financial crisis

**JEL classification:** G12, C14, E43, E62, H62, H63

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## 1 Introduction

The fact that financial crisis can spread quickly and easily across borders and yet regulation is still set largely in a national context is commonly known. Equally known but with real and more dangerous implications is, most countries pay little attention to the sum total of effects of economic shock beyond their own borders (financial nationalism), a situation prone to strong reactions from other countries that can lead to a conflict. When a central bank is printing money (quantitative easing) to bolster domestic growth, the increased supply of a currency will push down its price, the exchange rate. When the government actively intervenes in foreign-exchange markets, the same effect will happen with the exchange rate. For sure, these policy will have spillover effects on other countries. Feared by the resulting loss of export competitiveness, other countries may react by also taking measures to depress its currency. Such "competitive devaluation" problem can lead to a currency war.

The unprecedented policy response of the advanced economies to the 2008/2009 global financial crisis also create spillovers, albeit of a different form. What makes this time also more dramatic is that, it has struck at a time of great global interdependence. The ultra-easy money policy in the United States (US) and Europe, intended to stimulate their domestic economies, have created contagion effects on others particularly through massive capital flows and spillovers in the financial market. The highly interdependent financial market makes these effects not only greater than before but also more difficult to overcome, since troubles in one asset class could transmit to other asset classes. When bonds market in a country is hit by a major shock in the European bonds market, for example, the entire financial market could be affected; equity market may be under pressure, currency market can feel the pinch, and money market may become unstable. The latter can cause liquidity crunch with broader repercussions on credits and the rest of the economy. Furthermore, instability in one country's asset classes can transmit across borders, causing markets in other countries more volatile.

In this paper, we delve into the contagion story where spillovers from a shock in the bonds market in the US after the Lehman Brothers collapse, and in Europe following the subsequent Eurozone crisis, are felt across the Asian financial markets. Although in general the latter have become more resilient to external shocks, thanks to the lessons learned from the 1997/1998 crisis, we argue that the shock and volatility spillovers from the US and European bonds markets are quite significant. The effect of the global crisis works not only through trade channel as many have claimed. Financial contagion is alive and kicking.

After discussing the dynamics of bonds yields in the next two sections, we present the method and approach to measure the shock and volatility spillovers. In particular, we use multivariate GARCH models with a Baba-Engle-Kraft-Kroner (BEKK) specification that has an attractive property where the conditional variance-covariance matrix is positive definite. They are applied to three distinct models: direct spillovers from bonds in mature markets to bonds in Asian market, indirect spillovers from bonds in mature market to other asset classes in Asian markets, and cross-market spillovers from bonds market in one Asian country to financial markets in other Asian countries.

## 2 Crisis, yield and volatility trends

The starting point of spillovers is the movement in bond yields, which measure return on bond, and are inversely related to prices. As our focus is on the impact of the Lehman shock in September 2008 and the subsequent Eurozone crisis, the origins of the shock we picked are classified into two: first, those represent less-risky assets, i.e., US Treasuries, German Bunds, and EU composite government bonds with 5–10 year maturities; second, those represent more-risky assets, i.e., US and EU high-yield corporate bonds with similar maturities. The affected Asian asset classes are the 5–10 year benchmark government bonds.[1] To the extent that the Japanese government bond market (the largest in the entire region) is also affected by the global market turmoil and plays a significant role in the rest of Asia's financial markets, we subsequently test the cross-market spillovers by using Japanese government bond as the origin of the shock.

As clearly seen in Figure 1A, the combined shocks and the global market turmoil following the Lehman collapse rattled both mature and emerging market economies. US and EU high-yield corporate bond prices tumbled and investors demanded higher risk premium to hold them during that period. Bond prices recovered and yields fell during the subsequent period. But the recovery was short-lived and mild. As the economic crisis in Greece deepened, bond prices again fell sharply and yields jumped to a new high in September 2011.

The contagion on the Asian markets can be seen in Figure 1B. During the 2008/2009 Lehman crisis, governments had to offer higher rates to investors to buy bonds of Republic of Korea, Malaysia and Thailand. Yields on government securities in those countries increased by as much as 2% points, while those in Indonesia and the Philippines by as much as 9% and 4% points, respectively. Notice also from the Figure that the yield trend of government bond in these two countries closely followed that of high-yielding US corporate bond, reflecting how investors classified government bond in Indonesia and the Philippines as high-yielding or riskier assets than their other Asian peers.

During the Lehman shock in the fall of 2008, Indonesia's rupiah bond market was the worst hit – as domestic rupiah bond prices plunged. The Indonesian

1 With liquidity in local markets higher in the belly of the curve – usually around the 3–7 year bracket – 5-year bonds for Asian debt are used, except for the Japanese case where we use 10-year bond yields.

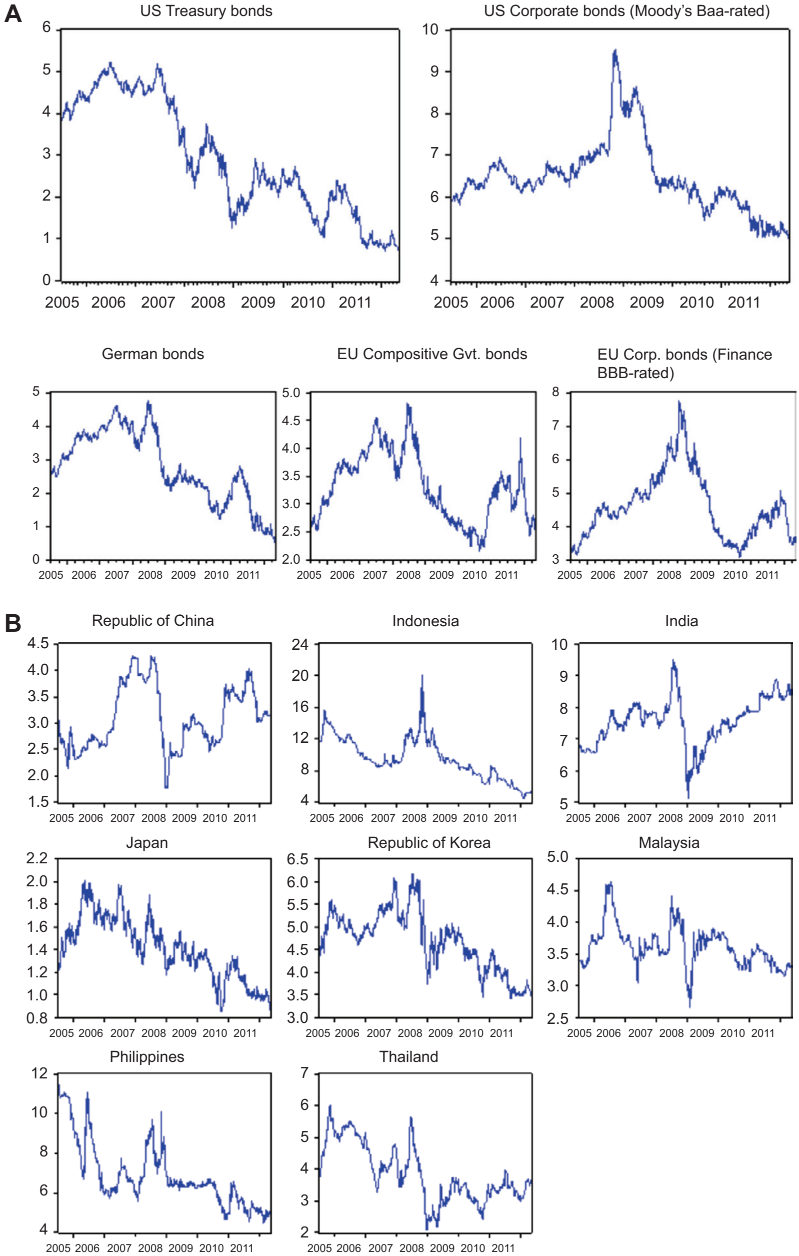



**Figure 1:** (A) Yield trends for the EU, Germany, and the US. (B) Benchmark government bond yields of selected Asian countries.
EU=European Union, US=United States.
Source: Bloomberg LP.

bond yield curve, which shows different yields for different maturities of government debt instruments, shifted upward reflecting the higher cost of government borrowing across the range of debt instruments offered by it. The spike in borrowing costs was also driven by fears of economic slowdown along with rising domestic inflation and sudden flight of foreign portfolio investors from the local bond market.[2] In fact, the abrupt withdrawal of foreign investors led to a significant drop in domestic trading activities. As trading in the local bonds slumped and market turned volatile, Indonesia had to cancel all scheduled government bond sales in the last quarter of 2008.

Similar rise in yields and volatility are observed in other Asian markets. In Korea, increased risk aversion by foreign investors amid liquidity shortage pushed up bond yields on government bonds. Authorities responded aggressively with fiscal stimulus packages, slashing lending rates, and improving liquidity by reducing issuance of central bank bonds, providing more dollars through currency swap agreements and boosting the Bank Recapitalization Fund to improve capital available to banks.[3]

In China, to sell bonds with shorter maturity the government had to pay more than 2% points than prior to the September 2008 shock. However, a massive fiscal stimulus package, a slew of interest rate cuts, lowering reserve requirements to inject more cash in the domestic financial system, and falling consumer price inflation during February–March 2009 led government's borrowing costs to come down to below the pre-September 2008 level.

In India, higher domestic inflation rates had already begun to exert an upward pressure on government's cost of borrowing. Yields on benchmark Indian government bonds reached a peak of 9.5% in mid-July 2008. The failure of Lehman Brothers and the subsequent global developments followed by sharp reductions in policy rates resulted in a softening of government security yields coupled with higher turnover in the secondary market. However, the increased

**2** Rising international prices of food and other commodities, including oil, aggravated the inflation pressure during that period.

**3** Due to evaporation of global liquidity, foreign currency borrowing conditions in Korea were severely worsened. In response, the Bank of Korea (BOK) used its foreign reserves and proceeds of its currency swaps with the US Federal Reserve to supply some US$26.6 billion liquidity through Competitive Auction Swap Facility and Competitive Auction Loan Facility. BOK also established a US$30 billion swap arrangement with the US Federal Reserve on October 30, 2008. As the pressures continued, the BOK subsequently entered into a 180 billion yuan/38 trillion won swap arrangement with China's central bank (PBC), and expanded the arrangement with Bank of Japan (BOJ) from US$3 billion to US$20 billion. Yet, the "power" of financial market spillovers remained unmatched, as clearly shown by the trends of currency swap rates and interest rate swap and the rapid widening of credit spread on corporate and bank bonds.

borrowing requirements by the central and state governments on account of various countercyclical fiscal measures taken to stimulate the economy resulted in a huge supply of government securities impacting on local interest rates. The yield, which had touched a low of 5.1% on 5 January 2009, rose again to around 7.2% in early September 2009 on account of concerns over excess supply and inflationary expectations.

India's central bank (RBI) subsequently employed a combination of measures involving monetary easing and the use of innovative debt management tools to ensure that there was enough liquidity in the market to support the government market borrowing program. As a result, there was a decline in the government's cost of borrowings during 2008–2009 for the first time in 5 years (Sinha 2010).

Temporary shortage of liquidity in the interbank and corporate debt markets at the peak of post Lehman crisis also raised some funding costs in Japan, but financing conditions gradually returned to normal, including as a result of action by the authorities to support credit and liquidity.

In general, market participants in Asia remained confident with policy measures taken following the Lehman crisis, and they also believed that those measures are only temporary (Turner 2012). To some degree, this lessened the upward pressure on longer-term yields as national authorities made clear that fiscal stimulus would be withdrawn as circumstances allowed. This also helped containing the yield fluctuations ("volatility spillovers"). But as the debt crisis in Europe deepened, Asian bond prices fell and yields rose again to near levels reached in September 2008. Risk premiums spiked again in Indonesia and Korea as foreign investors withdrew and domestic investors were reluctant to fill in the gap.[4] Contagion also spread to China, where the bond market was hurt by fears of a sharper-than-expected growth slowdown and rising market uncertainty. As a result, cost of government borrowing for short-term debt rose nearly 40 basis points between end-July and end-August 2012. Volatility in Asian markets once again reared its ugly head.

## 3 Isolating volatility spillover

It is known that the notion of spillovers can be slanted by clustering phenomenon if we simply compare the yield movements visually as done above. This is

4 Yields of government bonds in Indonesia, Malaysia, and Thailand began to edge up in July and August 2012 on renewed uncertainty – despite the continued decline in US and German bond yields.

because a large movement in prices can lead to persistent price amplification. Observing unprocessed (raw) data may also suffer from the "leverage effect" – where a drop in bond value increases its leverage and volatility.

Thus, to measure the yield volatility more properly we employ generalized autoregressive conditional heteroskedastic (GARCH) models. The first step is to use a univariate GARCH to extract conditional variances of the shock sources (yields of 5-year US Treasuries, German Bunds, US and EU high-yield corporate bonds) and of the affected markets (yields of local currency government bond in eight East Asian countries).[5] Volatility patterns of yield returns across different periods are indicated by the conditional variances obtained from a univariate AR(1) – GARCH(1, 1) process. The mean equation is an AR(1) process

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \varepsilon_t$$

where $y_t$ is the bond yield return. Variances of the returns obtained from the mean equation are then modeled as a GARCH process to generate the conditional variances. The GARCH equation is represented by

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \alpha_{t-1}^2,$$

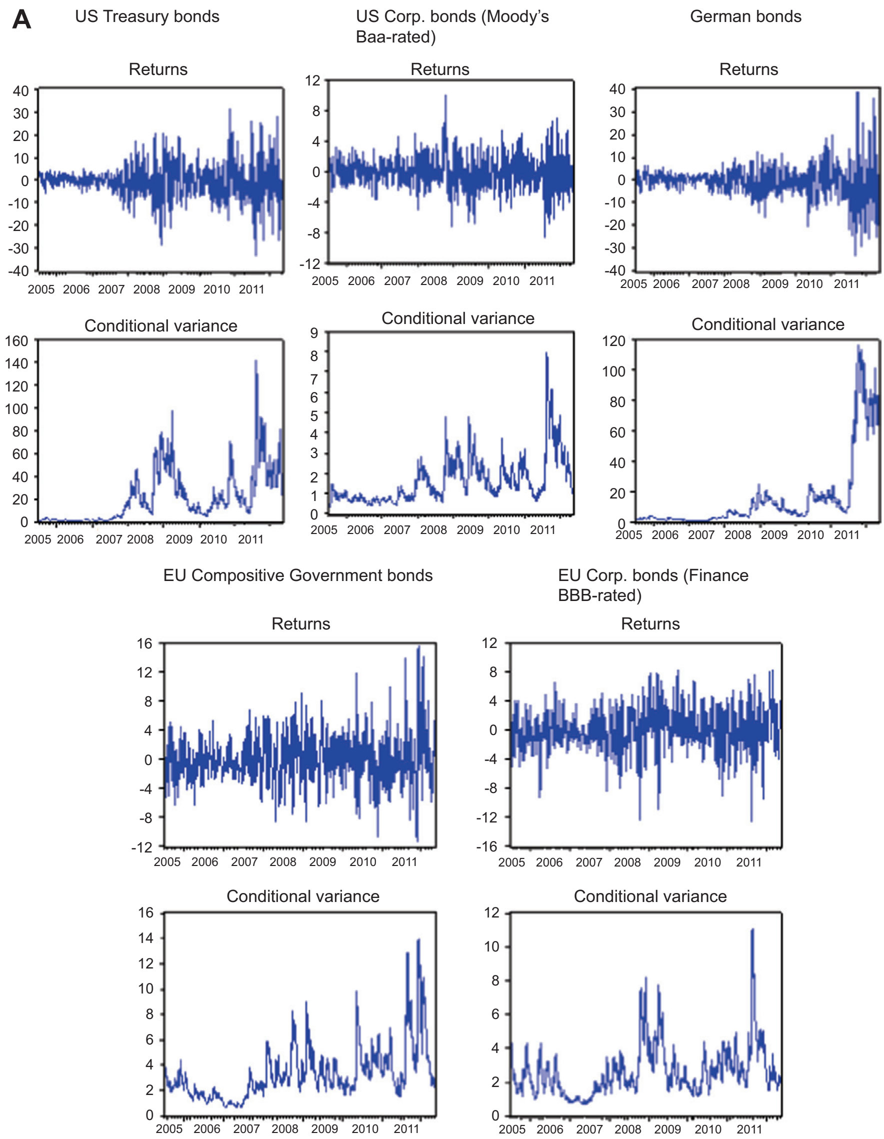
where $\sigma_t^2$ is conditional variance of the time-series and $\varepsilon_t^2$ is squared residuals. The square of past residuals ($\varepsilon_{t-1}^2$) refers to the AR term and the lagged variances ($\sigma_{t-1}^2$) refer to the GARCH term.

It is clear from Figure 2A that yields on 5-year US Treasury and German Bunds were affected by the event of Lehman shock in the Fall of 2008. The volatility spike for German Bunds was smaller compared with that for US Treasuries. Together with the observed downward trends, the large variations in yield returns for these two markets imply a "flight to safety and liquidity" strategy adopted by investors. They took refuge in less risky government securities in the US and Germany as the global market turbulence shook their confidence. At the same, the volatilities of US and EU high-yield corporate bond return began to rise as investors were less willing to hold or buy these higher risk assets.

In the run-up to the sovereign debt crisis in Europe, volatility spiked again. The region's fiscal woes only intensified financial market uncertainty, resulting in prolonged variability in bond yields/returns. The EU composite bond – which contains all rated sovereigns from the Eurozone – was more volatile than say

5 Conditional variances are used instead of unconditional variances to address the issue of volatility clustering and leverage effect that are commonly observed in high frequency financial data.

the German government bond as it reflected the large risk premium investors attached to Portugal, Ireland, Italy, and Spain. These heightened fluctuations spiked substantially in September 2011.




(**Figure 2:** Continued)

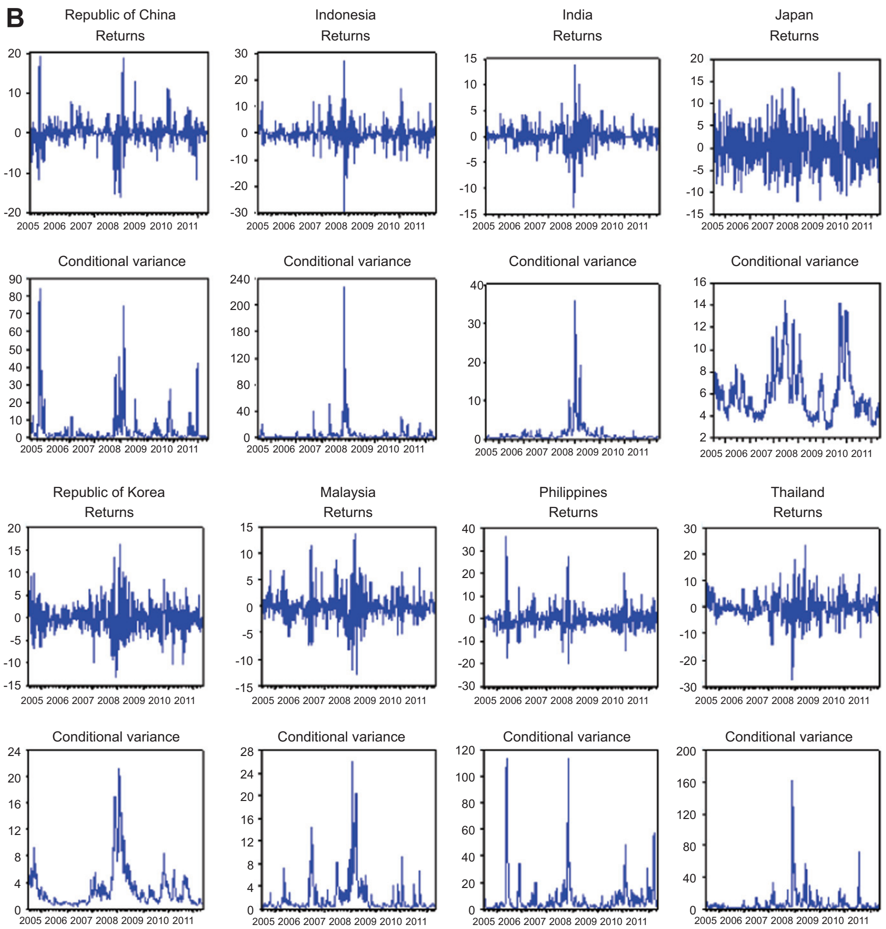



**Figure 2:** (A) Volatility patterns of Government and Corporate bonds – the EU, Germany, and the US. (B) Volatility patterns of Government bonds of selected Asian countries.
EU=European Union, US=United States.
Source: Authors' calculation.

How did this affect Asia? As shown in Figure 2B, markets in some countries showed spikes in volatility during the Lehman collapse and the Eurozone crisis. Volatilities in yield returns may not have been as sharp or persistent as compared with those of the shock sources. Nonetheless, it is clear that there remains underlying yield volatility in Asian markets despite yields leveling off since the end of 2008.

## 4 Existing literature and methodology

In using high-frequency data as in most financial applications, standard errors and confidence intervals estimated by conventional procedures may give a false sense of precision even-though the resulting coefficients are unbiased. Moreover, the amplitude of (daily) financial asset returns likely to vary over time, creating "volatility clustering." GARCH models accommodate conditional variances and heteroskedastic error terms common in financial time series data, while multivariate GARCH models have been used to investigate volatility and correlation transmission and spillover effects in contagion (Bae, Karolyi, and Stulz 2003; Tse and Tsui 2002).

Given the highly integrated financial system, shocks to an individual asset market may affect asset markets in other countries. Such spillovers have been detected during past financial crises in mature and developing markets alike (Rai 2011). Market interdependencies in average price and returns of assets have actually been studied early on (see, e.g., Eun and Shim 1989; Koch and Koch 1991). The possibility of volatility transmission between asset markets due to contagion was proposed by King and Wadhwani (1990). They found evidence of an international volatility contagion effect where the correlation between market movements in different countries and general levels of volatility were positively related. Shiller, Konya, and Tsutsui (1991) offered an explanation that agents do not assess the economic implications of news; they simply respond by "shooting first and asking questions later." Engle, Ito, and Lin (1990) examined the phenomenon of volatility clustering in foreign exchange markets making the distinction between what they termed "heat wave" and "meteor shower" effects: the former referring to volatility which is not transmitted to other markets, the latter is volatility transferred between markets. Using foreign exchange data, the authors found more evidence for meteor shower than for heat wave behavior.

Early econometric studies looked into whether co-movements between assets become stronger during crisis than during tranquil periods. Some also investigated the direction of international spillovers (Hartmann, Straetmans, and Vries 2004). There is also a large literature examining the international transmission of equity market volatility, and a growing literature examining the international transmission of bond market volatility (Steeley 2006). Studies examining the interdependence of market volatility typically use ARCH time series models. Hamao, Masulis, and Ng (1990) discovered that shocks to the volatility of financial market returns in one country could influence both the conditional volatility and the conditional mean of the returns in another country. Koutmos and Booth (1995) observed asymmetric volatility relations between the financial markets in the US, the UK and Japan, where the influence of negative shocks was different in both scale and direction to positive shocks. This volatility asymmetry is also known as "leverage effect," since an increase in a firm's debt to equity ratio will lead to both an increase in the risk and volatility (Bekaert and Wu 2000; Black 1976; Brailsford and Faff 1993; Christie 1982).[6]

Studies on the interdependence of bond markets are fewer in number. Ilmanen (1995) used a linear regression model to forecast the excess returns of international bonds, where excess returns were found highly correlated indicating considerable integration among international bond markets. Borio and McCauley (1996) and Domanski and Kremer (2000) investigated international bond market spillovers in volatile periods. Borio and McCauley examined a number of factors that might explain the rise in volatility during the bond sell-off in 1994. Investigating four types of market dynamics: volatility persistence, relationships in the direction of market movements, foreign disinvestment, and volatility spillover effects from other markets, they found that volatility persistence had strong explanatory power. Capital flows are also found to cause a rise in bond volatility, especially for countries experiencing a sell-off of government bonds.

Domasnski and Kremer (2000) addressed the issue on how asset price linkages can be measured when they are subject to periodic changes during periods of market stress. They found that the more tranquil periods are influenced by independent country-specific shocks. During these times international price correlation tends to be lower. But strong turbulence usually lashes global markets like a "meteor shower." Asset prices in high volatility periods are driven by a common factor, the international shock and therefore a higher degree of co-movement.

Dungey et al. (2006) studied the contagion in international bond markets during the Russian and the LTCM (Long Term Capital Management) crises. Using a latent factor model and a new data set spanning bond markets across Asia, Europe and the Americas, they quantified the contribution of contagion to the spread of these crises. The maximum amount of contagion experienced by any of the countries investigated is about 17% of total volatility in bond spreads, with the main effects due to the Russian crisis. The results also show that both emerging and developed markets experienced contagion during the period.

Given the serial correlation in our asset returns time series, the mean equation is initially represented by a vector autoregressive (VAR) process. The conditional mean equation is represented as

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**6** The GARCH modeling framework has also been applied to analyze the volatility spillovers in a single country; see, e.g., Conrad, Kaul, and Nimalendran (1991) and Kroner and Ng (1998) for the US equity market, and Chelley-Steeley and Steeley (1996) for the UK equity market. While past shocks to the volatility of large firm portfolios appeared to influence the volatility of small firm portfolios, the reverse was not found to be the case. Alli, Thapa, and Yung (1994) applied the same technique to examine volatility spillovers between different sectors of the US oil industry.

$$R_t = \alpha + \sum_{k=1}^{p} \Phi_p R_{t-k} + \varepsilon_t \qquad (1)$$

where $R_t$ is an $N\times1$ vector of week-on-week returns for each of the benchmark local currency bond yields, $\Phi_p$ is a matrix of parameters, and $(\varepsilon_t|I_{t-1})$~$(0, H_t)$ is an $N\times1$ vector of random errors or innovations in each local currency bond market at time $t$ given past information $I_{t-1}$ (Karolyi 1995).

The diagonal elements of the matrix $\Phi_p$ measure own market lagged impacts; while the off-diagonals capture the effect of lagged return in one market on the current movement in the market being observed (cross-mean spillovers).

A critical element in the specification of VAR models is the determination of the VAR lag length.[7] To determine the optimal lag-length for our mean equation VAR estimations, Schwarz information criterion (SIC) is used, the resulting average VAR lag order of which is shown in the appendix.

The resulting residual vectors, $(\varepsilon_t|I_{t-1})$~$(0, H_t)$, of the VAR mean equations are modeled as multivariate GARCH, where the $N\times N$ conditional variance-covariance matrix $H_t$ is estimated using the unrestricted version of the Baba–Engle–Kraft–Kroner (BEKK) model defined in Engle and Kroner (1995). The BEKK model has the attractive property that the conditional variance-covariance matrix is positive definite by construction. The model has the form

$$H_t = CC' + \sum_{j=1}^{q} \sum_{k=1}^{K} A'_{kj}(\varepsilon_{t-j}\varepsilon'_{t-j})A_{kj} + \sum_{j=1}^{p} \sum_{k=1}^{K} B'_{kj} H_{t-j} B_{kj} \qquad (2)$$

where $A_{kj}$, $B_{kj}$, and $C$ are $N\times N$ parameter matrices, and $C$ is lower triangular. The decomposition of the constant term into a product of two triangular matrices is to ensure positive definiteness of $H_t$. The BEKK model is covariance stationary if and only if the eigenvalues of $\sum_{j=1}^{q} \sum_{k=1}^{K} A_{kj} \otimes A_{kj} + \sum_{j=1}^{p} \sum_{k=1}^{K} B_{kj} \otimes B_{kj}$, where $\otimes$ denotes the Kronecker product of two matrices, are less than one in modulus. The summation limit $K$ determines the generality of the process. Whenever $K>1$, an identification problem arises because there are several parameterizations that yield the same representation of the model. Engle and Kroner (1995) give conditions for eliminating redundant, observationally equivalent representations.

With this specification, the conditional variances and covariances depend on the lagged values of all the conditional variances and covariances across bond

7 Lütkepohl (1993) argued that over-fitting (selecting a higher order lag length than the true lag length) causes an increase in the mean-square forecast errors of the VAR, and under-fitting the lag length often generates auto-correlated errors.

market returns, as well as the lagged squared errors and cross-products of error terms (Brooks 2008). In this specification, $C$ is a matrix of $c_{lm}$ constants, $A_{kj}$ is a parameter matrix of $a_{lm}$ elements indicating the extent of market shock spillovers, and $B_{kj}$ is a parameter matrix of $b_{lm}$ elements capturing market volatility spillovers between markets $l$ and $m$.

To further illustrate, we consider the bivariate first order ($K$=1) BEKK model

$$H_t = CC' + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B \tag{3}$$

Expanding this to matrix representation

$$\begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} c_{11} & c_{21} \\ c_{12} & c_{22} \end{bmatrix} + \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t-1} \\ \varepsilon_{2,t-1} \end{bmatrix} [\varepsilon_{1,t-1} \;\; \varepsilon_{2,t-1}] \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{21} \\ b_{12} & b_{22} \end{bmatrix} \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

where $h_{12,t}=h_{21,t}=h_{cov,t}$

The representations of the main diagonal elements of the conditional variance-covariance matrix $H_t$ would be

$$\begin{aligned} h_{11,t} &= (c_{11}^2 + c_{12}^2) + (a_{11}^2\varepsilon_{1,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}^2\varepsilon_{2,t-1}^2) \\ &\quad + (b_{11}^2 h_{11,t-1} + 2b_{11}b_{21}h_{cov,t-1} + b_{21}^2 h_{22,t-1}) \end{aligned} \tag{4}$$

$$\begin{aligned} h_{22,t} &= (c_{21}^2 + c_{22}^2) + (a_{12}^2\varepsilon_{1,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{22}^2\varepsilon_{2,t-1}^2) \\ &\quad + (b_{12}^2 h_{11,t-1} + 2b_{12}b_{22}h_{cov,t-1} + b_{22}^2 h_{22,t-1}) \end{aligned} \tag{5}$$

where $h_{11,t}$ and $h_{22,t}$ are the conditional variance equations of markets $l$=1 and $m$=2.

The parameters of interest in our study are the off-diagonal elements of $A$ and $B$ – corresponding to the $a_{lm}$ (*where* $l \neq m$) elements indicating the extent of market shock spillovers, and $b_{lm}$ (*where* $l \neq m$) elements capturing the market volatility spillovers between markets $l$ and $m$.

Estimation of the BEKK model – via maximum likelihood (ML) – involves somewhat heavy computations due to several matrix inversions. The number of parameters, $(p+q)KN^2+N(N+1)/2$, in the full BEKK model is still quite large. Obtaining convergence may therefore be difficult because log-likelihood is not linear in parameters. There is the advantage, however, that the structure automatically ensures positive definiteness of $H_t$, so this does not need to be imposed separately. Partly because numerical difficulties are so common in the estimation of BEKK models, it is typically assumed $p$=$q$=$K$=1 in applications.[8]

Three variants of the above multivariate GARCH model are used in the study.

## 4.1 Direct spillover

In estimating the direct volatility transmissions between US and EU markets to local currency bond markets in Asia, bivariate versions of the BEKK model are estimated. For the impact from the Lehman collapse, the US Treasury and US corporate bond markets are used as the two main sources of shocks and spillovers. For the Eurozone crisis, perturbations in German Bunds, EU composite government bonds, and the European corporate bonds (mainly financial sector) markets are used to examine their fallout on emerging East Asia's domestic debt markets. Three periods are defined: (i) pre-crisis, from July 2005 to August 2008, (ii) Lehman collapse, from September 2008 to March 2009, and (iii) peak of Eurozone debt crisis, from September 2011 to May 2012.

## 4.2 Indirect spillover

Since substantial cross-asset market transmissions and interactions can occur during times of heightened market uncertainty and stress, adding to the overall instability of the financial system, we extend our analysis to investigate the channels through which the shocks and volatilities of source markets get transmitted to Asian local currency bond markets. The aim is to identify significant direct or indirect channels of shock and volatility propagation.

A broader view of financial market interactions, spillover, and contagion during the Lehman collapse and Eurozone debt crisis periods also necessitates the use of multivariate GARCH (MV GARCH) analysis of a group of domestic financial markets partnered with an international source market. In line with the previous estimation technique, this exercise also employs the unrestricted version of the BEKK model ($p$=$q$=$K$=1) to estimate the 5×5 conditional variance-covariance matrix $H_t$.

**8** Most financial time series volatility clustering characteristics are aptly modeled by a GARCH(1,1) process (i.e., $p$=$q$=1). This implies that conditional variances and covariances depend on one period lag values of all the conditional variances and covariances across bond market returns, as well as one period lag squared errors and cross-products of error terms. Setting $K$=1 allows mathematical tractability of the model.

For the impact from the Lehman collapse, the US Treasury (**UST BM**) and US high-yield corporate (**USC BM**) bond markets are used as the two main sources of shocks and spillovers. For the Eurozone debt crisis, perturbations in the German Bund (**Ger BM**), EU composite government bond (**EUCG BM**), and European corporate bond (**EUC BM**) markets are used to examine their fallout on selected Asian asset markets.

The group of domestic markets considered are the local bond (**BM**), domestic equity (**EQM**), domestic currency (**FXM**), and domestic money (**MM**) markets.

The time periods are defined the same as above. Although the emphasis is on shock and volatility spillovers, particularly in local bond markets, the results are rich enough to show shock and volatility persistence and spillovers within domestic markets, and from source market to domestic markets.

## 4.3 Cross-country-market spillover

To illustrate cross-Asian-market spillovers, we employ an MV GARCH analysis of a group of domestic financial markets partnered with the Japanese government bond market. In line with the previous estimation technique, this exercise also employs the unrestricted version of the BEKK model ($p$=$q$=$K$=1) to estimate the 5×5 conditional variance-covariance matrix $H_t$.

The group of domestic markets considered are the local bond (**BM**), domestic equity (**EQM**), domestic currency (**FXM**), and domestic money (**MM**) markets.

We applied the models described above on daily data extracted from Bloomberg covering the period between June 2005 and May 2012 (covering before the GFC through the on-going Eurozone crisis). Week-on-week return data are used and continuously compounded returns are computed as

$$r_{i,t} = \log\left(\frac{y_{i,t}}{y_{i,t-5}}\right) \times 100$$

Week-on-week returns are computed for the price indicators in the source markets and in each of the asset classes of the Asian markets. The week-on-week returns are all computed from daily end of period prices and as such refer to end of trading day returns. The price indicators of the source markets are the yields on 5-year US Treasury bond; 5-year German Bund; 5-year EU composite government bond; US high-yield corporate bond (with a Baa rating from Moodys); and EU high-yield corporate bond (mainly financial sector bonds). Benchmark 5-year government bond yields of the PRC, Indonesia, Republic of Korea, Malaysia, Philippines, and Thailand are used as price indicators of the Asian bond markets.

The composite stock price indexes of the Asian stock markets namely Shanghai Composite (PRC); Jakarta Stock Exchange (Indonesia); Korea Stock Exchange (Korea); Kuala Lumpur Stock Exchange (Malaysia); Philippine Stock Exchange (Philippines); and the Stock Exchange of Thailand (Thailand) indicate equity prices. Currency prices are given by the exchange rate on the domestic currency (of each of the Asian markets) against the US dollar (LCY/USD) where a negative return points to an appreciation of the local currency. Overnight interbank lending rates on domestic currency borrowings are the price indicators of the money market.

# 5 Analysis

## 5.1 Direct spillovers

The results of the bivariate GARCH models show that while Asian government bond returns and volatilities are influenced by dynamics of their own markets, contagion effects from the Lehman and Eurozone crises were also significant in some countries. The shock spillovers in 2008/2009 following the Lehman collapse affected six Asian markets – China, Thailand, Malaysia, Korea, India, and the Philippines, whereas spillovers from the Eurozone crisis in 2011 affected four markets – China, Thailand, Korea, and Indonesia (Tables 1 and 2). The strongest shock spillovers during the Eurozone crisis were in China. In fact, the shock spillover coefficients throughout emerging Asia were generally higher during the 2008/2009 global financial crisis than during the 2011 Eurozone crisis, except for China.

During the 2008/2009 crisis, the most significant shock spillovers came from the US high-yield corporate bond market, which affected local bond markets in Korea, Malaysia, India, and the Philippines. Similarly, there were shock spillovers from high-yielding EU corporate bond markets into local bond markets in China and Thailand, and from the EU Composite Bond Index into China. In terms of volatility spillovers, perturbations in high-yield US corporate bond markets significantly affected local bond markets in China in the 2008/2009 crisis, whereas during the Eurozone crisis, volatile EU corporate (financial) bonds significantly affected markets in the Philippines and Thailand.

These results highlight the uncertainty surrounding the transmission of spillovers from the ongoing debt crisis in the Eurozone to Asia's local currency bond markets. Such transmissions imply that Asian authorities should be prepared for any possible disruptive impacts of spillovers from mature markets.

**Table 1:** Shock and volatility spillovers (coefficients significant at 5% level).

| Source market | Shock spillover | | | | Volatility spillover | | | |
|---|---|---|---|---|---|---|---|---|
| | Lehman collapse | | Eurozone debt crisis | | Lehman collapse | | Eurozone debt crisis | |
| | Asian Mkt | Coefficient | Asian Mkt | Coefficient | Asian Mkt | Coefficient | Asian Mkt | Coefficient |
| US Treasury Bond (10-year) | Malaysia | 0.1013 | | | | | | |
| | Thailand | 0.0523 | | | | | | |
| | China | 0.0149 | | | | | | |
| US High-Yield Corporate Bond | Malaysia | 0.4867 | | | China | 0.8546 | | |
| | Korea | 0.3875 | | | | | | |
| | India | 0.2541 | | | | | | |
| | Philippines | 0.2021 | | | | | | |
| German Bunds (10-year) | | | China | 0.0139 | | | India | 0.0007 |
| | | | Thailand | 0.0092 | | | | |
| | | | Indonesia | 0.0053 | | | | |
| | | | Korea | 0.0011 | | | | |
| EU Composite Government Bond (10-year) | | | China | 0.1619 | | | Japan | 0.8064 |
| | | | | | | | Korea | 0.0869 |
| | | | | | | | Thailand | 0.0353 |
| EU High-Yield Corporate Bond | | | China | 0.0956 | | | Philippines | 1.9797 |
| | | | Thailand | 0.0426 | | | Thailand | 0.3600 |

Source: Results of model calculation.

**Table 2:** Shock and volatility persistence (coefficients significant at 5% level).

| Source market | Own shock persistence | | | | Own volatility persistence | | | |
|---|---|---|---|---|---|---|---|---|
| | Lehman collapse | | Eurozone debt crisis | | Lehman collapse | | Eurozone debt crisis | |
| | Asian Mkt | Coefficient | Asian Mkt | Coefficient | Asian Mkt | Coefficient | Asian Mkt | Coefficient |
| US Treasury Bond (10-year) | Thailand | 0.3013 | | | Japan | 0.9905 | | |
| | Indonesia | 0.1384 | | | Philippines | 0.8849 | | |
| | India | 0.1303 | | | Korea | 0.8808 | | |
| | China | 0.1281 | | | Indonesia | 0.8416 | | |
| | Korea | 0.0883 | | | China | 0.7849 | | |
| | Philippines | 0.0843 | | | India | 0.7128 | | |
| | | | | | Thailand | 0.6589 | | |
| | | | | | Malaysia | 0.5795 | | |
| US High-yield Corporate Bond | Thailand | 0.3969 | | | Indonesia | 0.8464 | | |
| | India | 0.2888 | | | Philippines | 0.8207 | | |
| | China | 0.1352 | | | Korea | 0.7942 | | |
| | Indonesia | 0.1343 | | | Thailand | 0.6674 | | |
| | Philippines | 0.1198 | | | Malaysia | 0.6556 | | |
| | Malaysia | 0.0580 | | | China | 0.5574 | | |
| | Korea | 0.0480 | | | India | 0.5315 | | |
| German Bunds (10-year) | | | Indonesia | 0.3037 | | | Korea | 0.8562 |
| | | | Malaysia | 0.1359 | | | China | 0.8340 |
| | | | Philippines | 0.0923 | | | India | 0.8159 |
| | | | Korea | 0.0880 | | | Malaysia | 0.7330 |
| | | | India | 0.0840 | | | Indonesia | 0.7185 |
| | | | Japan | 0.0821 | | | Thailand | 0.5692 |
| | | | China | 0.0638 | | | | |

(**Table 2:** Continued)

| Source market | Own shock persistence | | | | Own volatility persistence | | | |
|---|---|---|---|---|---|---|---|---|
| | Lehman collapse | | Eurozone debt crisis | | Lehman collapse | | Eurozone debt crisis | |
| | Asian Mkt | Coefficient | Asian Mkt | Coefficient | Asian Mkt | Coefficient | Asian Mkt | Coefficient |
| EU Composite Government Bond (10-year) | | | Indonesia | 0.1694 | | | Philippines | 0.8859 |
| | | | India | 0.1194 | | | Thailand | 0.8331 |
| | | | Malaysia | 0.0846 | | | China | 0.8161 |
| | | | Philippines | 0.0633 | | | Indonesia | 0.8016 |
| | | | Korea | 0.0559 | | | India | 0.7984 |
| | | | Thailand | 0.0337 | | | Malaysia | 0.7455 |
| | | | | | | | Korea | 0.6476 |
| EU High-yield Corporate Bond | | | China | 0.2155 | | | Korea | 0.8649 |
| | | | Indonesia | 0.2010 | | | India | 0.8373 |
| | | | Malaysia | 0.1535 | | | Malaysia | 0.7918 |
| | | | Japan | 0.0920 | | | Indonesia | 0.7606 |
| | | | India | 0.0799 | | | China | 0.6928 |
| | | | Philippines | 0.0653 | | | Japan | 0.5501 |
| | | | Korea | 0.0469 | | | | |

Source: Results of model calculation.

The shock and volatility persistence within own markets was generally similar during the two crises. However, the own shock persistence in the Philippines and Thailand was stronger in 2008/2009 than in 2011, while the impact of the Eurozone crisis was stronger in Indonesia, Korea, and Malaysia. In terms of own volatility persistence, in both crises the results of all countries were significant, although EU corporate bonds appear to transmit the most significant volatility to Korea, Malaysia, Indonesia, and China.

These results clearly show that prior-period shock and volatility have manifested themselves on own market performance.[9] The persistence of prior-period volatilities are more distinct than the prior-period shock, suggesting that market perception about return fluctuations is more pronounced during bouts of financial market stress.

## 5.2 Indirect spillovers

Figure 3 shows the significant channels of shock and volatility spillovers from sources in mature markets, and across Asian financial markets, as implied by our multivariate GARCH estimates.[10]

Apart from the direct shock spillovers from the US and EU government bond markets into Asian local bond markets, the multivariate GARCH estimates reveal significant transmission of shock spillovers during both the Lehman and Eurozone crises in domestic money markets. During the Lehman crisis, there were significant spillovers into domestic money markets in China, Indonesia, Korea, the Philippines, and Thailand. During the Eurozone crisis, in addition to the China, Indonesia, the Philippines, and Thailand, there was also a direct spillover into the Malaysian money market. The results highlight how the liquidity crunch that occurred in mature markets during the Lehman and Eurozone crises spilled over into emerging Asia's domestic money markets and affected the region's capital market transactions.

The shocks delivered by US and EU government bond markets to Asian domestic money markets eventually found their way to Asian foreign exchange (FX) markets and local bond markets. There was significant spillover feedback

**9** Unlike in the preceding section, however, here the volatility clusters that tend to appear during a crisis are taken into account (reflected in the larger coefficient).

**10** See Appendix for the Tables A1 and A2 of significant shock and volatility spillover coefficients.

| Lehman crisis period | Eurozone debt crisis period |
|---|---|
| The channels of shock spillovers are<br>1. UST BM → MM<br>FXM ↔ MM<br>FXM → BM<br><br>2. USC BM → BM<br>USC BM → EQM<br>EQM → BM | The channels of shock spillovers are<br>1. EUCG BM → MM<br>BM ↔ MM ↔ FXM ↔ BM<br><br>2. Ger BM → BM<br>Ger BM → MM<br><br>3. EUC BM → BM<br>EUC BM → EQM |
| The channels of volatility spillovers are<br>1. UST BM → BM<br>UST BM → EQ M<br>BM ↔ EQM ↔ FXM ↔ BM<br><br>2. USC BM → BM | The channels of volatility spillovers are<br>1. EUCG BM → BM<br>↗ EQM<br>EUCG BM → FXM<br>↘ MM<br>↗ MM<br>2. Ger BM → EQM → BM<br>↘ FXM<br>3. EUC BM → FXM<br>BM ↔ EQM ↔ FXM ↔ BM |

**Figure 3:** Observed shock and volatility spillovers across Asian financial markets.
Note: → shows unidirectional spillover; ↔ shows two-way market feedback and/or spillover.
Source: Results of model calculation.

between the domestic FX and money markets.[11] Since most Asian banks have substantial holdings of local government bonds, any instability in the FX and money markets translates into instability in local bond markets.

On the other hand, the US and Eurozone corporate bond markets delivered shocks directly to Asian local bond markets. This reinforces investor perceptions that most Asian government bonds are in the same asset class as high-risk corporate bonds in mature markets.

**11** To further investigate claims of tightening in the US$-funding market during the height of the global financial crisis in 2008/2009, we have used the MV GARCH model to observe spillovers between US$ SIBOR and local money markets. Results show significant shock and volatility spillovers between the two funding markets, implying that instability is transmitted across onshore and offshore money markets. The region's FX markets also showed significant shock effects on bond markets, particularly when the source of shock and volatility spillovers was US Treasuries.

During the Lehman crisis, the US high-yield corporate debt market impacted Indonesia, Korea, Malaysia, and the Philippines. The disturbances in the high-yield corporate market in the Eurozone generated shock spillovers in these same four markets, as well as in China and Thailand.

The US and EU corporate bond markets also cause shock spillovers in Asian domestic equity markets, which further supports the high-yield classification of Asian assets by global investors. There has also been a significant shock spillovers from emerging Asia's domestic asset markets into local bond markets. During the Lehman crisis, for example, equity markets showed significant shock spillovers into local bond markets, particularly when viewed alongside the high-yield US corporate bond market.

The US and EU government bond markets have direct volatility spillovers into Asian local bond markets. Their values are generally larger than the shock spillovers. During the Lehman crisis, there were direct volatility spillovers from US Treasuries into the bond markets of China, Indonesia, the Philippines, and Thailand. During the Eurozone crisis, in addition to the China, Indonesia, the Republic of Korea, and Thailand, volatility in the EU composite government bond market also spilled over into Malaysia.

During the Lehman collapse crisis, the US corporate bond market had significant volatility spillovers into all local bond markets included in this exercise. Moreover, there was a high degree of spillover across domestic financial markets, suggesting heightened contagion during this crisis period.

During the Eurozone debt crisis, the EU government bond market showed significant volatility spillovers not just into Asian local bond markets, but also into domestic equity, FX, and money markets, demonstrating the real and broader threat of financial market contagion from mature markets.

## 5.3 Cross-country markets spillovers

In this section we look at cross-market spillovers in the mature bond markets through the shock and volatility spillovers from the Japanese Government Bond (JGBs) markets to other regional markets. The results are shown in Table 3.

Despite the rise in public debt, JGB yields have remained low and stable, supported by steady inflows from the household and corporate sectors, a high level of domestic ownership of JGBs, and safe-haven flows from investors seeking refuge from volatile mature global markets.

In the near-term, the JGB market faces domestic and external risks. Domestically, a decline in the funding supply from the corporate sector, where financial surpluses are abnormally high, could push up JGB yields. An increase in market

**Table 3** Shock and volatility spillover from the Japanese Government Bond (JGB) Market.

| Lehman collapse | | | | | | | | Eurozone sovereign debt crisis | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BM** | | **EQ** | | **FX** | | **MM** | | **BM** | | **EQ** | | **FX** | | **MM** | |
| **Country** | **Coeff.** | **Country** | **Coeff.** | **Country** | **Coeff.** | **Country** | **Coeff.** | **Country** | **Coeff.** | **Country** | **Coeff.** | **Country** | **Coeff.** | **Country** | **Coeff.** |
| **Shock spillover to** | | | | | | | | | | | | | | | |
| China | 0.48364 | India | 0.10798 | | | Indonesia | 0.06831 | Korea | 0.00782 | Korea | 0.00857 | Indonesia | 0.00078 | India | 0.00746 |
| Philippines | 0.18402 | Korea | 0.02186 | | | India | 0.11682 | Thailand | 0.00951 | | | India | 0.00603 | | |
| | | Philippines | 0.06975 | | | Malaysia | 0.04963 | | | | | Korea | 0.00124 | | |
| | | Thailand | 0.03065 | | | Thailand | 0.00030 | | | | | | | | |
| **Volatility spillover to** | | | | | | | | | | | | | | | |
| China | 0.12008 | China | 0.79109 | China | 0.00010 | Indonesia | 0.00852 | Indonesia | 0.00241 | China | 0.09530 | China | 0.00056 | Indonesia | 0.00093 |
| Malaysia | 0.09945 | India | 0.62809 | Korea | 0.21907 | | | Korea | 0.03360 | Thailand | 0.15165 | Indonesia | 0.00716 | India | 0.00340 |
| Philippines | 0.09478 | Korea | 0.39716 | Malaysia | 0.00136 | | | | | | | India | 0.00436 | Malaysia | 0.02705 |
| | | Malaysia | 0.05817 | Philippines | 0.01961 | | | | | | | Korea | 0.00951 | | |
| | | Thailand | 0.02364 | Thailand | 0.00106 | | | | | | | Phillippines | 0.00082 | | |

Note: Coefficients significant at 5% level. Coeff., Coefficent volatility could also push banks to shorten the maturity of their JGB holdings or reduce their JGB exposure to limit losses. Given the high correlation between yields on JGBs and other sovereign debt, sudden rises in global risk premia could spillover and affect the JGB market. All these factors could eventually contribute to a sustained rise in yields, worsen the public debt dynamics, and pose a risk to financial stability.

Over the medium-term, the market's capacity to absorb new debt is likely to diminish as the population ages and risk appetite recovers. Japan's large pool of domestic savings, stable investor base, and high share of domestic ownership of JGBs has helped maintain stability in the JGB market. But these favorable factors could diminish over time as an aging population reduces household savings and risk appetite recovers. Without a significant policy adjustment, the stock of gross public debt could exceed household financial assets in around 10 years, at which point domestic financing may become more difficult to sustain (Lam and Tokuoka, IMF 2011).

Following the Lehman collapse, the JGB market had significant shock spillovers into domestic equity and money markets in Asia, and volatility spillovers into domestic equity and FX markets. The liquidity crunch that ensued after the Lehman collapse diverted investor attention to safe-haven assets like JGBs and prompted them to hold relatively large cash positions as protection against market turmoil and uncertainty. Our model's results show that investor movement into the JGB market led to heightened volatility in emerging Asian money markets and caused investors to flee the region's equity markets. In particular, both shock spillovers and volatility spillovers were significant in China and the Philippines, but spillovers also hit the money and FX markets in other Asian countries (Table 3).

During the Eurozone debt crisis, the JGB market showed significant shock and volatility spillovers not only into the bond markets in Korea and Thailand, but also into domestic FX markets in other Asian countries. Prior to the Eurozone crisis, Japan was on a path of deflation and was experiencing a strong yen. Considering the significant FX spillovers, any sudden transition from a strong to weak yen will likely be a serious shock to Japan's regional neighbors.[12]

**12** Many studies (Xie 2012, Ito 1999) have cited the yen's devaluation from 1995 to 1997 – in part due to correction of the excess rise in the previous years and also in line with weak domestic fundamentals – as one of the factors triggering the 1997/1998 Asian financial crisis.

# 6 Conclusions

The 2008/2009 global crisis originated in the advanced economies and the policy response to it reverberated throughout the world. The financial sector's reverberation has been felt particularly in many emerging market economies including those in Asia in the forms of massive capital flows and financial market volatility. While Asian financial markets have come a long way since the 1997/1998 Asian crisis, our analysis reveals that in some countries the markets are significantly affected by the Lehman shock in 2008 and the on-going Eurozone debt crisis. Using the GARCH model with BEKK specifications, we have detected not only that the direct shock and volatility spillovers are significant, but the spillover effects are also transmitted through cross-asset markets as well as cross-country asset markets. In particular, the shocks in the US and Eurpean bonds market affect not only domestic bond markets but also other asset markets. Apart from direct and indirect spillovers, it is also found that there is cross-market contagion as illustrated by spillovers from the Japanese government bond markets. Arguably, contagion into one market finds its way into other markets.

For emerging economies affected by the unilateral policy in advanced countries, among lessons to be learned are: First, persistence of volatility could reduce the attractiveness of bond market – as it directly impacts investors' perception of the collateral value of local currency bonds. Second, any significant shock spillovers and spike in volatility can lead to volatile capital outflows from local markets – with a direct impact on liquidity. The risks are likely to escalate if reversals of flows occur, for example due to tightening of monetary policy in advanced economies (tapering quantitative easing policy). Third, the spillovers and persistence of volatility could raise borrowing costs and lead private sector to postpone using local markets to fund new investment. Lastly, given the heightened risks of capital flows in the midst of growing financial integration, domestic policies alone are likely inadequate. The provision of regional safety nets, complemented by the existing global safety nets, becomes critical to better stave off pressures from the spread of contagion.

Like in the case of currency war, domestic financial instability caused by a unilateral policy in some countries may lead to a reaction from others. Spillovers through capital flows like those detected in our analysis highlight the importance of coordination and cooperation among policy makers and regulators at the domestic, regional, and global levels. Without effective cooperation, and given the growing financial nationalism in time of crisis, if domestic policies are inadequate to deal with external pressures countries may react strongly, and conflict situation can emerge.

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# Appendix – Indirect spillovers

**Table A1:** Shock spillovers and persistence (significant at the 5% level).

**Lehman collapse**

| Recepient Market | Country \ Variable | BM (Source Market) | EQ (Source Market) | FX (Source Market) | MM (Source Market) | US Treasury (Source Market) |
|---|---|---|---|---|---|---|
| BM | CHN | | 0.0897 | | | 0.0759 |
| BM | IDN | 0.1663 | | 0.2687 | | |
| BM | JAP | 0.1689 | 0.0228 | 0.1375 | | |
| BM | KOR | | 0.0439 | 0.1166 | 0.0039 | |
| BM | PHI | 0.2708 | | 1.5465 | | |
| BM | THA | 0.4092 | 0.0083 | 3.4587 | | |
| EQ | CHN | | 0.3517 | 10.2232 | | 0.0299 |
| EQ | IDN | 0.0767 | 0.2217 | | | |
| EQ | IND | 0.1861 | | | | 0.0274 |
| EQ | JAP | | | 0.3685 | | |
| EQ | KOR | | 0.0302 | | | |
| EQ | PHI | 0.0226 | 0.2207 | | | 0.0064 |
| EQ | THA | 0.0094 | 0.1088 | 2.3164 | | |
| FX | CHN | 0.0001 | | 0.1703 | 0.0001 | |
| FX | IDN | 0.0096 | 0.0492 | 0.0579 | | |
| FX | IND | 0.0163 | 0.0043 | 0.2117 | 0.0002 | 0.0027 |
| FX | JAP | 0.0359 | 0.0180 | 0.2812 | 0.0007 | 0.0300 |
| FX | KOR | | | 0.2046 | | |
| FX | THA | 0.0009 | | 0.1085 | 0.0040 | 0.0001 |
| MM | CHN | 0.8424 | 0.1672 | 60.1780 | | 0.0578 |
| MM | IDN | 0.0004 | 0.0027 | 0.0188 | 3.0717 | 0.0040 |
| MM | IND | 0.1811 | | 8.3987 | 0.5025 | 0.0289 |
| MM | JAP | | 2.1821 | 6.9263 | 0.2369 | |
| MM | KOR | 0.1285 | 0.1667 | | 0.7429 | 0.0144 |
| MM | PHI | 0.0725 | | | 0.0516 | 0.0446 |
| MM | THA | 0.0001 | 0.0028 | 0.4005 | 11.1316 | 0.0014 |

| Recepient Market | Country \ Variable | BM (Source Market) | EQ (Source Market) | FX (Source Market) | MM (Source Market) | US Corp (Source Market) |
|---|---|---|---|---|---|---|
| BM | CHN | 0.0192 | 0.0493 | 22.0932 | 0.0227 | |
| BM | IDN | | 0.1792 | 0.1334 | 0.2383 | 0.3183 |
| BM | IND | 0.1569 | | | 0.0007 | |
| BM | JAP | | 0.0035 | | 0.0007 | 0.0577 |
| BM | KOR | | 0.0719 | 0.0736 | | 0.3066 |
| BM | MAS | 0.0274 | | | 0.2732 | 0.3196 |
| BM | PHI | 0.0534 | 0.2961 | | 0.0093 | 0.0659 |
| BM | THA | 0.0822 | 0.0429 | 12.0191 | 0.3489 | |
| EQ | CHN | | 0.0388 | 28.8173 | | 0.5073 |
| EQ | IDN | | 0.7445 | | 0.5255 | 0.3084 |
| EQ | IND | 0.0774 | | | | 0.5898 |
| EQ | JAP | | | 1.7047 | | |
| EQ | KOR | 0.0539 | 0.0180 | 0.0612 | | 0.2843 |
| EQ | MAS | | 0.0456 | | 0.0086 | 0.0378 |
| EQ | PHI | 0.1764 | 0.0852 | | 0.0820 | |
| EQ | THA | | 0.1917 | 1.6150 | | |
| FX | CHN | 0.0000 | | 0.5707 | 0.0000 | 0.0013 |
| FX | IDN | 0.0158 | 0.0284 | 0.2974 | | |
| FX | IND | | | 0.0637 | | |
| FX | JAP | 0.0404 | | | | 0.0285 |
| FX | KOR | 0.0087 | | 0.1890 | | 0.0270 |
| FX | MAS | | 0.0034 | 0.0923 | 0.0039 | 0.0022 |
| FX | PHI | 0.0134 | | | 0.0022 | |
| FX | THA | 0.0005 | | 0.0186 | 0.0028 | |
| MM | CHN | | 0.4052 | | 0.0236 | |
| MM | IDN | | | | 0.0986 | |
| MM | IND | 1.8715 | 0.5085 | 45.0108 | 3.1321 | |
| MM | JAP | | 1.0028 | | 0.2093 | |
| MM | KOR | 0.0412 | 0.0533 | | 0.8638 | 0.1765 |
| MM | MAS | 0.0580 | 0.1121 | 2.2800 | 2.2344 | 0.8813 |
| MM | PHI | 0.2445 | 0.5423 | 1.5327 | 0.1682 | |
| MM | THA | 0.0000 | | 0.0005 | 4.5599 | 0.0012 |

**EU sovereign debt crisis**

| Recepient Market | Country \ Variable | BM (Source Market) | EQ (Source Market) | FX (Source Market) | MM (Source Market) | EU composite government bond (Source Market) |
|---|---|---|---|---|---|---|
| BM | CHN | 0.2187 | 0.0135 | | 0.0004 | 0.0318 |
| BM | IDN | 0.0675 | 0.0211 | 0.2591 | 0.0873 | |
| BM | IND | 0.0364 | 0.0042 | 0.0081 | 0.0012 | |
| BM | JAP | | 0.0278 | 0.2853 | 0.0008 | 0.0119 |
| BM | KOR | | 0.0203 | | 0.0489 | |
| BM | MAS | 0.2043 | 0.0018 | | | |
| BM | PHI | 0.1304 | | | 0.0022 | |
| BM | THA | 0.0707 | 0.0120 | | | |
| EQ | CHN | | | | | 0.0084 |
| EQ | IDN | 0.0039 | 0.0079 | 0.0211 | | |
| EQ | IND | | 0.0085 | | 0.0032 | |
| EQ | KOR | | 0.0923 | 0.2658 | | 0.0023 |
| EQ | MAS | | 0.1490 | | | |
| EQ | PHI | | 0.1395 | 0.1984 | 0.0062 | |
| EQ | THA | | 0.0855 | 0.1687 | | |
| FX | CHN | 0.0003 | 0.0003 | 0.0591 | | |
| FX | IDN | 0.0010 | 0.0018 | 0.1866 | 0.0015 | 0.0005 |
| FX | IND | 0.0853 | | 0.0439 | | |
| FX | JAP | 0.0172 | | | | 0.0019 |
| FX | KOR | 0.0004 | 0.0026 | 0.0131 | 0.0025 | |
| FX | MAS | | 0.0097 | 0.1029 | 0.0173 | |
| FX | PHI | 0.0006 | 0.0042 | 0.0250 | | 0.0006 |
| FX | THA | | 0.0011 | 0.0630 | | |
| MM | CHN | | | 189.4008 | 0.0912 | 0.5252 |
| MM | IDN | 0.2031 | 0.1316 | 0.0388 | 4.0678 | 0.0323 |
| MM | IND | | | 0.0793 | 0.8537 | |
| MM | JAP | 1.7560 | 23.6016 | 135.6977 | 0.0478 | 13.2824 |
| MM | KOR | 0.0443 | | | 0.0706 | |
| MM | MAS | 0.0666 | 0.0641 | 0.1070 | 0.0323 | 0.0098 |
| MM | PHI | 0.0224 | 0.1325 | 1.3572 | 0.1286 | 0.0123 |
| MM | THA | 0.0031 | 0.0125 | 0.1149 | 5.0510 | 0.0001 |

| Recepient Market | Country \ Variable | BM (Source Market) | EQ (Source Market) | FX (Source Market) | MM (Source Market) | German Bunds (Source Market) |
|---|---|---|---|---|---|---|
| BM | CHN | 0.2277 | | 10.7284 | | 0.0002 |
| BM | IDN | 0.1676 | | 0.0599 | 0.2775 | |
| BM | IND | | 0.0041 | | 0.0003 | 0.0001 |
| BM | JAP | 0.0261 | | | 0.0039 | |
| BM | KOR | | 0.0101 | | | 0.0007 |
| BM | MAS | 0.1847 | | | | 0.0000 |
| BM | PHI | 0.0375 | | | | |
| BM | THA | | 0.0318 | | 0.7992 | 0.0004 |
| EQ | CHN | | | 5.4637 | | 0.0002 |
| EQ | IDN | 0.0208 | 0.0271 | 0.3054 | | |
| EQ | IND | 0.3763 | | | | |
| EQ | JAP | | 0.0108 | | 0.0003 | 0.0053 |
| EQ | KOR | | 0.0462 | 0.6158 | | |
| EQ | MAS | 0.1251 | 0.1081 | | 0.1037 | |
| EQ | PHI | 0.0125 | 0.1621 | | 0.0031 | |
| EQ | THA | 0.0095 | 0.0430 | | | |
| FX | CHN | | 0.0003 | 0.0270 | 0.0000 | |
| FX | IDN | | 0.0147 | 0.0328 | 0.0045 | |
| FX | IND | 0.0754 | 0.0084 | 0.0196 | 0.0020 | |
| FX | JAP | 0.0203 | | 0.0649 | | 0.0005 |
| FX | KOR | 0.0020 | | 0.0189 | | |
| FX | MAS | 0.0266 | 0.0511 | | 0.0104 | |
| FX | PHI | | 0.0070 | | | |
| FX | THA | 0.0031 | | | | |
| MM | CHN | 1.5956 | 4.0717 | 113.1182 | 0.1254 | |
| MM | IDN | 0.4800 | 0.0154 | 0.4742 | 1.3250 | 0.0002 |
| MM | IND | | | | 0.7917 | |
| MM | JAP | 2.4092 | 29.3805 | 5.3603 | 0.4265 | 1.4701 |
| MM | KOR | 0.0431 | | | 0.3739 | |
| MM | MAS | | | 0.0950 | 0.2687 | 0.0004 |
| MM | PHI | 0.0263 | 0.2376 | 5.7405 | 0.1726 | 0.0007 |
| MM | THA | 0.0000 | 0.0000 | | 1.7978 | 0.0000 |

| Recepient Market | Country \ Variable | BM (Source Market) | EQ (Source Market) | FX (Source Market) | MM (Source Market) | EU corp (Source Market) |
|---|---|---|---|---|---|---|
| BM | CHN | 0.5181 | | 1.6111 | | 0.0315 |
| BM | IDN | 0.2389 | | 0.3717 | | 0.0181 |
| BM | IND | | 0.0057 | 0.0284 | 0.0020 | 0.0107 |
| BM | JAP | 0.0331 | 0.0979 | | 0.0041 | |
| BM | KOR | 0.0078 | 0.0325 | | 0.4358 | |
| BM | MAS | 0.1769 | | 0.0186 | | 0.0018 |
| BM | PHI | 0.1091 | | 1.8479 | 0.0106 | 0.0165 |
| BM | THA | | 0.0371 | | | 0.0426 |
| EQ | CHN | | 0.0404 | 10.4054 | 0.0005 | 0.0199 |
| EQ | IDN | 0.0928 | 0.5270 | 2.7579 | 0.1290 | |
| EQ | IND | | 0.0290 | 0.0496 | | 0.0103 |
| EQ | JAP | 0.0401 | | | | 0.0580 |
| EQ | KOR | 0.0095 | 0.1327 | 0.4387 | 0.0528 | 0.0164 |
| EQ | MAS | | 0.0256 | | | 0.0020 |
| EQ | PHI | 0.0071 | 0.2860 | 0.1313 | | |
| EQ | THA | | 0.0556 | 0.0692 | | 0.0088 |
| FX | CHN | 0.0002 | | | 0.0000 | |
| FX | IDN | 0.0018 | 0.0150 | | 0.0174 | |
| FX | IND | | 0.0071 | | 0.0035 | |
| FX | JAP | 0.0065 | | 0.0718 | 0.0002 | |
| FX | KOR | | | | | 0.0033 |
| FX | MAS | | | | 0.0123 | |
| FX | PHI | | | 0.0645 | | |
| FX | THA | | | | 0.1341 | |
| MM | CHN | | 2.2416 | | 0.2051 | 2.9383 |
| MM | IDN | 0.1021 | | | 0.3203 | 0.0074 |
| MM | IND | 0.0660 | | 0.0908 | 0.7240 | |
| MM | JAP | 1.5971 | 42.4461 | | 0.6493 | 14.9843 |
| MM | KOR | 0.0481 | | | 0.1783 | 0.0034 |
| MM | MAS | | | 0.1572 | 0.0757 | 0.0300 |
| MM | PHI | 0.0818 | 0.0730 | 1.0690 | 0.0844 | |
| MM | THA | 0.0000 | 0.0000 | 0.0006 | 1.5821 | 0.0000 |

BM=local bond market, CHN=People's Rep. of China, EQ=domestic equity market, FX=domestic currency market, IDN=Indonesia, IND=India, JAP=Japan, KOR=Rep. of Korea, MM=domestic money market, MAS=Malaysia, PHI=Philippines, THA=Thailand.
Source: Authors' calculations.

**Table A2:** Volatility spillovers and persistence (significant at the 5% level).

**Lehman collapse**

| Recepient Market | Country | Source Market: BM | EQ | FX | MM | US Treasury |
|---|---|---|---|---|---|---|
| BM | CHN | 0.2049 | 0.0581 | | 0.0251 | 0.0104 |
| | IDN | 0.8642 | 0.2312 | | | 0.0301 |
| | IND | | 0.0663 | 1.3502 | | 0.0818 |
| | JAP | 0.0772 | | | 0.0084 | 0.0622 |
| | KOR | 0.4739 | 0.4852 | 0.1425 | | |
| | PHI | 0.3056 | | | 0.0114 | 0.0320 |
| | THA | 0.6111 | | | | 0.0296 |
| EQ | CHN | 0.1263 | 0.0684 | 29.9823 | | 0.0976 |
| | IDN | | 0.0485 | | | 0.0659 |
| | IND | 0.7818 | 0.5321 | | | |
| | JAP | 0.5355 | 0.2915 | | 0.0231 | |
| | KOR | 0.6017 | 0.7370 | 0.6771 | | |
| | PHI | 0.2771 | | 5.1957 | 0.0430 | 0.0348 |
| | THA | | 0.9007 | 4.6840 | | 0.0073 |
| FX | CHN | | | 0.6400 | 0.0000 | |
| | IDN | 0.0077 | 0.1030 | 0.6870 | | |
| | IND | 0.0248 | | | | |
| | JAP | | 0.0221 | | | |
| | KOR | 0.1698 | 0.1509 | 1.0927 | | |
| | PHI | | 0.0038 | | 0.0076 | |
| | THA | 0.0009 | 0.0037 | | | 0.0023 |
| MM | CHN | 0.5049 | | | 0.3318 | 0.0275 |
| | IDN | | 0.0006 | | 0.0634 | |
| | IND | | | 2.3364 | 0.5939 | |
| | JAP | 5.9677 | | | 0.0360 | 0.5637 |
| | KOR | | | | 0.4310 | |
| | PHI | 0.1295 | 1.5485 | | 0.4055 | |
| | THA | 0.0001 | 0.0003 | 0.0018 | 0.0044 | |

| Recepient Market | Country | Source Market: BM | EQ | FX | MM | US Corp |
|---|---|---|---|---|---|---|
| BM | CHN | 0.4538 | 0.1795 | 5.3379 | | 0.2189 |
| | IDN | 0.3975 | | 1.9775 | | 1.0190 |
| | IND | 0.6803 | 0.0212 | 0.1115 | 0.0003 | 0.0640 |
| | JAP | | | 1.6467 | 0.0049 | 1.1330 |
| | KOR | 0.6173 | | | 0.0083 | 0.1149 |
| | MAS | 0.5539 | 0.4939 | 1.1450 | 0.1253 | 0.2550 |
| | PHI | 0.2803 | | 0.4188 | 0.0644 | 0.3909 |
| | THA | | 0.1436 | 54.7333 | 0.0171 | 0.6379 |
| EQ | CHN | 0.4971 | 0.3819 | 32.5360 | 0.0806 | |
| | IND | 0.1264 | | 4.3411 | 0.0014 | 0.1559 |
| | JAP | | 0.7713 | 0.7706 | 0.0044 | |
| | KOR | 0.1186 | 0.6367 | 0.0504 | 0.0012 | 0.3565 |
| | MAS | 0.1915 | 0.4009 | | 0.0199 | 0.0794 |
| | PHI | | | 10.0616 | | |
| | THA | 0.0540 | 0.6036 | | 0.0576 | 0.2226 |
| FX | CHN | 0.0001 | 0.0000 | 0.2788 | 0.0000 | 0.0005 |
| | IDN | 0.0235 | 0.0492 | 0.4500 | | 0.1028 |
| | IND | 0.0055 | 0.0081 | 0.7804 | | |
| | JAP | 0.0950 | 0.0112 | 0.0505 | 0.0062 | |
| | KOR | 0.0321 | 0.0041 | 0.9108 | 0.0005 | |
| | MAS | | 0.0469 | 0.1057 | | 0.0608 |
| | PHI | 0.0049 | 0.0345 | 0.4771 | | 0.0373 |
| | THA | 0.0056 | 0.0012 | 0.0267 | 0.0006 | 0.0215 |
| MM | CHN | | 0.0857 | | 0.5498 | 0.6732 |
| | IDN | | | | 0.3648 | |
| | IND | | 0.0808 | 1.8931 | 0.0197 | |
| | JAP | 9.3564 | | 7.9226 | 0.1508 | |
| | KOR | | | | 0.4687 | |
| | MAS | | | | | 0.0073 |
| | PHI | 0.2699 | | 2.7186 | 0.0977 | 3.8639 |
| | THA | | 0.0000 | | 0.0247 | |

**EU sovereign debt crisis**

| Recepient Market | Country | Source Market: BM | EQ | FX | MM | EU composite government bond |
|---|---|---|---|---|---|---|
| BM | CHN | | 0.3137 | 16.7443 | | 0.0240 |
| | IDN | 0.0466 | 0.0241 | 4.0671 | | 0.0016 |
| | IND | 0.0236 | 0.0031 | 0.1322 | | 0.0315 |
| | JAP | | 0.5846 | 0.8998 | 0.0007 | |
| | KOR | | 0.1019 | 0.2127 | 3.2675 | 0.0523 |
| | MAS | 0.7894 | 0.0035 | 0.0200 | 0.0053 | 0.0017 |
| | PHI | 0.8540 | 0.0606 | | 0.0027 | |
| | THA | 0.5891 | 0.0052 | | | 0.0415 |
| EQ | CHN | 0.4638 | 0.1322 | 19.4184 | | |
| | IDN | 0.4103 | 0.4027 | | 0.0359 | 0.0024 |
| | IND | | 1.0440 | 0.0355 | | |
| | JAP | 0.0704 | 0.8632 | | | 0.1756 |
| | KOR | | 0.8594 | 0.0300 | 0.1894 | |
| | MAS | | 0.1086 | 0.7452 | | 0.0594 |
| | PHI | | 0.0432 | 6.5700 | 0.0140 | 0.0385 |
| | THA | | 0.8932 | 0.0379 | | 0.0137 |
| FX | CHN | 0.0015 | | 0.1208 | | 0.0011 |
| | IDN | 0.0726 | 0.0893 | 0.1589 | | |
| | IND | 1.5789 | 0.0207 | 0.0289 | 0.0017 | |
| | JAP | | 0.0241 | | 0.0002 | 0.0355 |
| | KOR | 0.0071 | 0.0010 | 0.8832 | 0.0778 | |
| | MAS | 0.1054 | | 0.5458 | | 0.0012 |
| | PHI | | 0.0844 | 0.2470 | | 0.0093 |
| | THA | | | 0.8225 | | 0.0030 |
| MM | CHN | | | 156.8631 | 0.3689 | 7.4547 |
| | IDN | | | | 0.0083 | |
| | IND | | | | 0.5589 | |
| | JAP | | 1.3395 | 34.6184 | 0.0288 | |
| | KOR | 0.1265 | 0.0264 | 0.0573 | 0.0245 | 0.0020 |
| | MAS | 0.0165 | | | | 0.0150 |
| | PHI | 0.0203 | | | 0.7158 | 0.0453 |
| | THA | | 0.0001 | | | |

| Recepient Market | Country | Source Market: BM | EQ | FX | MM | German Bunds |
|---|---|---|---|---|---|---|
| BM | CHN | 0.5360 | 0.0247 | 10.0487 | 0.0006 | |
| | IDN | 0.7053 | 0.0054 | | 0.3696 | |
| | IND | 0.4524 | | 0.2049 | 0.0003 | 0.0000 |
| | JAP | 0.2116 | 0.9774 | 0.4907 | 0.0003 | |
| | KOR | 0.5149 | 0.1193 | 0.2993 | | 0.0025 |
| | MAS | 0.8326 | | | | |
| | PHI | 0.8898 | | | | |
| | THA | 0.1615 | | 7.4780 | | 0.0025 |
| EQ | CHN | 0.0808 | 0.0587 | 57.0317 | 0.0020 | 0.0012 |
| | IDN | | 0.8929 | | | |
| | IND | 2.3149 | 0.2327 | 0.5138 | | 0.0005 |
| | JAP | 0.0336 | 0.4272 | 0.2652 | 0.0015 | 0.0172 |
| | KOR | 0.2293 | 0.9890 | | | 0.0002 |
| | MAS | | 0.2812 | 0.1585 | 0.2265 | 0.0009 |
| | PHI | | 0.6959 | 0.7921 | 0.0049 | |
| | THA | | 0.9166 | | | |
| FX | CHN | | 0.0087 | | 0.0000 | |
| | IDN | | | 0.8636 | 0.0051 | |
| | IND | 0.8819 | 0.0968 | 0.6695 | | |
| | JAP | | | 0.1691 | 0.0005 | 0.0005 |
| | KOR | 0.0283 | | 0.9160 | 0.0095 | 0.0000 |
| | MAS | | 0.0365 | 0.1146 | 0.0198 | 0.0003 |
| | THA | 0.0160 | 0.0145 | | | |
| MM | CHN | | 3.7219 | 676.3852 | 0.4909 | |
| | IDN | 0.0262 | 0.0028 | | 0.0203 | 0.0000 |
| | IND | | | 0.0413 | 0.5842 | |
| | JAP | 3.3099 | | 12.5211 | 0.1475 | |
| | MAS | 0.0775 | 0.3047 | 2.3164 | 0.1416 | |
| | PHI | | | 1.3549 | 0.6658 | 0.0003 |
| | THA | | 0.0000 | 0.0000 | 0.2853 | |

| Recepient Market | Country | Source Market: BM | EQ | FX | MM | EU corp |
|---|---|---|---|---|---|---|
| BM | CHN | 0.2880 | | 7.6736 | | 0.0329 |
| | IDN | 0.1062 | 0.0978 | 0.6723 | 0.1326 | |
| | IND | 0.2476 | | 0.0326 | | 0.0550 |
| | JAP | 0.2911 | | 2.4431 | | 0.1781 |
| | KOR | 0.2165 | | 0.2669 | 3.4559 | |
| | MAS | 0.7847 | | | 0.0068 | |
| | PHI | 0.6798 | | 0.3031 | 0.0073 | 0.0222 |
| | THA | 0.2057 | | | | |
| EQ | CHN | | | 44.1673 | | |
| | IDN | 0.0254 | 0.2389 | | 0.3135 | 0.2060 |
| | IND | | 0.6075 | 0.2980 | | |
| | KOR | 0.2018 | 0.1156 | 3.3536 | 0.6469 | |
| | MAS | 0.0040 | 0.8867 | | 0.0126 | |
| | PHI | | 0.6070 | | 0.0006 | 0.0133 |
| | THA | 0.0202 | 0.8968 | | | |
| FX | CHN | | 0.0077 | | | 0.0014 |
| | IDN | 0.0105 | 0.0090 | 0.4777 | 0.1033 | |
| | IND | 0.7489 | 0.1951 | 0.1605 | 0.0010 | |
| | JAP | | | 0.2262 | 0.0005 | |
| | KOR | 0.0407 | 0.2263 | 0.0589 | 0.0324 | |
| | MAS | | | 0.4124 | 0.0982 | 0.0082 |
| | PHI | 0.0007 | 0.0035 | 0.6481 | | 0.0204 |
| | THA | | | | | 0.0301 |
| MM | CHN | | | 379.4810 | 0.6553 | |
| | IDN | 0.3289 | 0.0962 | | 0.1054 | |
| | IND | | | | 0.5885 | |
| | JAP | 6.6316 | | | 0.0373 | 4.2792 |
| | KOR | 0.0559 | | | | 0.0210 |
| | MAS | 0.0452 | 0.2771 | 0.9354 | 0.1632 | |
| | PHI | 0.1018 | 0.0128 | | 0.7993 | |
| | THA | | | | 0.2954 | |

BM=local bond market, CHN=People's Rep. of China, EQ=domestic equity market, FX=domestic currency market, IDN=Indonesia, IND=India, JAP=Japan, KOR=Rep. of Korea, MM=domestic money market, MAS=Malaysia, PHI=Philippines, THA=Thailand.
Source: Authors' calculations.

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