Spillover effects of the 2007 subprime financial crisis on USA, EMU, China and Japan equity markets.

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Abstract

In this work we investigate the volatility spillover effects on four major in terms of capitalization international equity markets due to the 2007 subprime financial crisis. The equity markets under scrutiny are those of USA, EMU, China and Japan. The data sample frequency is daily and spans from August 1996 to April 2011. Employing a MGARCH model we find empirical evidence of increased volatility spillover effects in almost all markets after the USA subprime crisis. Specifically, the empirical results suggest that Japanese and EMU markets have been directly affected from the subprime crisis. However China's equity market has been mainly unaffected. China's equity market has been sensitive to spillover effects during the pre-crises period, partly explainable from the increasingly financial integration with the rest of the world. Moreover, the Japanese equity market exhibits strong spillovers with China and EMU equity markets revealing an indirect line of volatility transmission to EMU.

1. Introduction

The 2007 US subprime financial crisis and its consequences to international markets attracted great attention from academics, investors and policy makers. Already, there is a large literature investigating the theoretical and empirical mechanisms of international volatility transmission of crises. On the theoretical side, King and Wadhwani (1990), and Kaminsky and Schukler (1999) suggested an analysis based on revision of expectations[1] and herding[2] behaviour, respectively. Furthermore, more recently, Stevens (2008) has documented two types of channels for international transmission of crises: Firstly, there are the common shocks, whereby financial sectors in different countries are concurrently affected by the same shock. Secondly, there are the spillover effects that are transmitted among economies. Didier et al. (2007) proposed two types of spillover effects. The first type is transmitted via real economy effects such as international transmission of aggregate demand and trade flow effects. The second type of spillover effects is due to the interaction of capital markets. These effects are transmitted by asset market adjustments or by financial institutions, e.g. banks. This paper focuses on the second type of spillover effects empirically investigating equity volatility transmission due to 2007 US subprime crisis. On the empirical side, Wang and Lee (2009) report evidence that after the 1997 Asian crisis, spillover effects of the stock returns and stock return volatilities in the nine Asian stock markets increased while Baig and Goldfajn (1999) report evidence of spillover effects for four Asian financial markets. For the recent 2007 crisis an empirical study of Angkinand et al. (2010) indicates that the degree of interdependence and spillover effects peaked after the US subprime mortgage meltdown between USA and seventeen other developed economies.

In this study, we empirically investigate the volatility spillover effects and interdependences among four major in terms of capitalization, equity markets, namely the USA, EMU, Japan and China. To explore these effects we estimate and test a multivariate generalized autoregressive conditional heteroskedastic (MGARCH) model, see for instance, Shamiri et al. (2009), Saleem (2009) and Caporale et al. (2009). It is worth mentioning that while these studies encompass a BEKK-MGARCH specification, here we rely on a more parsimonious vector-diagonal model.

[1] The revision of expectations theory suggests the existence of feedback traders where asymmetric information could lead to the propagation of crises through portfolio rebalancing effects.

[2] Herding behavior emphasizes investors' beliefs that asset prices contain relevant information. Herding may encompass diverse phenomena such as bank runs, fickle investors and hot money.

An understanding of the magnitude and direction of linkages and spillover effects is an essential part of financial managers and policy makers' information set. From the financial managers' point of view, knowledge of markets interdependence is important in determining hedging and diversification of their international investment. Furthermore, from a policy maker's point of view, financial instability, such as a bank collapse and stock market crashes, are major issues that directly influence a country's welfare.

The rest of the paper is structured as follows. In section two we present an overview of market's main macroeconomic characteristics. In the third section we describe the data employed and their descriptive statistics. The econometric estimation method to estimate the volatility spillovers is stated in the fourth section. The empirical results are discussed in the fifth section. Last section concludes.

2. Overview of the Markets

Table 1 summarizes key annual macroeconomics market figures over the period 1996 to 2010 including: trade balance, direct investment abroad, portfolio investment assets (equities and dept assets), GDP and unemployment rate. These macroeconomic stylized facts can also rationalize the spillover effects. All indices are expressed in billion US-dollars and the dataset is extracted from the International Financial Statistics.

2.1. USA market characteristics

The main macroeconomic figure which distinguishes USA market from the other three markets under examination is the persistent trade balance deficit. The USA trade balance deficit has been increasing until the financial crisis. In addition to these facts, foreign direct investment and portfolio investment assets from abroad are high in the USA market. Gross domestic product was expanding, until the onset of financial crisis while unemployment rate exploded to 9.62 % in 2010. Moreover, USA is the largest importer and the largest investment region among the four markets.

2.2. EMU market characteristic

EMU market has a positive but volatile trade balance along the whole sample period exhibiting a slow decline after 2007. After 2008, gross domestic product had been declined, with a simultaneous increase in unemployment. It is worth mentioning the high investment from abroad, especially in dept security assets, a crucial channel of spillover transmission.

2.3. Japan market characteristics

Japan's macroeconomics figures reveal that the impact of crisis was deeper compared to the other markets. The most severe impact is the sharp decline of the trade balance, remaining however positive. Given that exports are the main driving force of Japan's economic activity; this can explain the observed decline of the GDP level. The increasing, although at still low level, unemployment reflects the effects of the crisis. Japan economy is heavily exposed to USA's, due to trade and investment policies.

2.4. China market characteristics

Among the four markets, the Chinese's market is most immune to the recent crisis. The direct investment and portfolio investment assets abroad show a slowdown in 2009. However, trade balance, direct investment abroad and portfolio investment assets have accelerated during the last years. China became the largest exporter and international investor among the four markets. As, one of the major world creditors China supports both USA and Euro-zone by purchasing bonds from these markets, especially during the recent financial crises period.

According to the above macroeconomic stylized facts we conclude that all under examination markets are interconnected through trade, investment and international relationships. So it is conjectured that these countries would be more susceptible to possible spillover effects from a crisis.

3. Data set description and summary statistics

The data set employed is daily, comprising 3912 observations for each market, and extends over fifteen years, spanning from April 1996 to April 2011. The data sample covers the global financial crisis initiated in August 2007[3]. Returns are US-dollar denominated[4], computed using stock indices from USA, EMU, Japan and China equity markets. All data are extracted from Datastream. The daily stock log-returns are evaluated by $r_{i,t} = \ln(p_t / p_{t-1})$ where p_t is the market total index (dividends included) expressed in US dollars at time t. Descriptive statistics for the pre crisis period and the after crisis period are reported in Table 1. The distributional properties of the return series appear to be non-normal due to excess kurtosis and fat tails.

[3] According to Cecchetti (2009) the real trigger came on Thursday August 9, the day that the large French bank BNP Paribas temporarily halted redemptions for three of its funds that held assets backed by US subprime mortgage debt.

[4] As suggested by Bekaert and Harvey (1995), calculating the returns in US dollars eliminates the local inflation.

Specifically, China market has a positive skewness, while US and EMU are negatively skewed. Japan has positive skewness in pre crisis period and negative thereafter. The kurtosis, in all markets, exceeds three, indicating a leptokurtic distribution. Excess kurtosis in equity returns has been well documented by a number of other studies including Bekaert and Harvey (1997). Test results of the null hypothesis of normality, using Jarque-Bera statistic, are reported in Table 2. With all *p*-values approximately zero to four decimal places, we reject the null hypothesis for all markets. A visual perspective of the return's volatility and the impact of 2007 crisis can be obtained from graphs of stock indices levels, daily returns and conditional variances for each market in Figure 1. The increase of volatility levels is noticeable in all markets after the 2007 crisis.

4. Econometric estimation of the spillover effects

First we filter out the linear structure of the returns series and decouple it from the conditional variance. To this end, we employ the VAR model:

$$r_t = \gamma + \sum_{s=1}^{n} a_s r_{t-s} + \varepsilon_t \,, \tag{1}$$

where r_t is the 4×1 column vector of equity markets returns, γ and a_s are, respectively, a 4×1 vector and 4×4 matrices of parameters and ε_t are 4×1 vectors of innovations. The lag length, $n=4$, is chosen by information criteria[5]. A frequently employed specification of the conditional variance is the Bollerslev, Engle and Wooldridge (1988) representation of the multivariate GARCH model. In vech form, the conditional covariance matrix is given by:

$$vech(H_t) = c + \sum_{j=1}^{q} A_j vech(u_{t-i}u_{t-i}^{'}) + \sum_{j=1}^{p} B_j vech(H_{t-j}) \,, \tag{2}$$

where $vech(\cdot)$ denotes the column stacking operator of the lower portion of a symmetric matrix. So, c is a $N(N+1)/2\times1$ vector and matrices A_j and B_j are of dimension $N(N+1)/2\times N(N+1)/2$. The vech representation of MGARCH while quite general possesses two drawbacks in applied work. First, the number of estimated parameters increases sharply with the dimensionality of the system. Moreover, the estimated conditional covariance matrices are not guaranteed to be positive definite.

[5] The VAR order length is selected by the final predicted error and the Akaike criterion. The results are available upon request.

For this reason, we consider the diagonal vech version of MGARCH(1,1) model[6] (Ding and Engle, 2001):

$$H_t = \overline{C}C' + \overline{A}A' \otimes u_{t-1}u'_{t-1} + \overline{B}B' \otimes H_{t-1}, \quad (3)$$

where $u_{i,t} \mid \Omega_{t-1} \sim student-(0, H_t, v)$, Ω_{t-1} is the information set at time $t-1$, $\otimes$ is the Hadamard (element by element) product. Given the rejection of the null hypothesis of normality we assume that the conditional probability density function of the errors follow the Student's t-distribution. This is a more plausible assumption that takes into account the fat tail behaviour of our daily data and, under correct specification, may improve the efficiency of the estimates. Since $\overline{C}C'$, $\overline{A}A'$ and $\overline{B}B'$ are all positive semi-definite, H_t will be positive definite for all t as far as the initial covariance matrix H_0 is positive definite.

Let $\omega_{ij} = (\overline{C}, C')_{ij}$, $\alpha_{ij} = (\overline{A}A')_{ij}$, $\beta_{ij} = (\overline{B}B')_{ij}$ then

$$h_{ijt} = \omega_{ij} + \alpha_{ij}u_{it-1}u_{jt-1} + \beta_{ij}h_{ijt-1}, \; i, j = 1, ..., N. \quad (4)$$

The elements of matrix A matrix measure the intensity of spillover effects among markets. While the elements of matrix B measure the persistence of conditional variance. The specification we finally estimate is the rank one version of the MGARCH(1,1) model which is of the form:

$$H_t = \overline{C}C' + aa' \otimes u_{t-1}u'_{t-1} + bb' \otimes H_{t-1}, \quad (5)$$

where a and b are $N \times 1$ vectors. Here we impose the restrictions the rank of parameter matrices A and B to be one. The model is estimated using Full Information Maximum Likelihood (FIML) methods with Student t-distributed errors. The FIML estimates are obtained by maximizing the log-likelihood $\sum_{t=1}^{T} l_t$, where

$$l_t = \log \frac{\Gamma\left(\frac{v+m}{2}\right)v^{m/2}}{(v\pi)^{m/2}\Gamma\left(\frac{v}{2}\right)(v-2)^{m/2}} - \frac{1}{2}\log(|H_t|) - \frac{1}{2}(v+m)\log\left[1 + \frac{\varepsilon_t' H_t^{-1}\varepsilon_t}{v-2}\right], \quad (6)$$

m is the number of equations, ε_t is the m vector of residuals and v is the degree of freedom.

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[6] It is generally agreed that a GARCH(1,1) specification with lag length one is adequate to capture the dynamics of conditional variance (Bollerslev et al., 1992).

5. Empirical results

We set the starting date of the financial crisis as the bankruptcy of BNP Paribas, at August ninth 2007. Several researchers used this date as the starting point namely: Acharya1 and Schnable (2010), Brunnermeier (2010) and Cecchetti (2009) among others. Based on this starting date we divide the sample into two sub-periods. Estimates of conditional volatility Eq.(5), for each sub-period, are reported in Tables 3 and 4. In line with several other studies, i.e. Worthington and Higgs (2004) and Saleem (2008), parameter estimates are statistically significant, for both sample periods, indicating the presence of strong GARCH effects. In figure 2 and 3 we graph the magnitude of own and cross spillover effects for the two sub-periods respectively.

5.1 Sample period: April 1996- 9 August 2007

Estimates of spillover effects, parameters A_{ij} are stated in Table 3 (to ease notation we do not discriminate here between parameters and parameter estimates). Estimates of own volatility effects, parameters $A_{ii}, i = 1,...,4$, reveal China's equity market strong own effects. For the cross volatility spillover estimates, we observe that $A_{24} > A_{14} > A_{34} > A_{12} > A_{23} > A_{13}$, i.e. spillover effects among the pair of countries EMU-China, USA-China and Japan-China are relatively stronger. Cross-volatility spillover estimates among the more mature markets of USA, Japan and EMU, namely A_{12}, A_{23}, A_{13}, are approximately the same, indicating an equivalent level of integration and interdependence. China's changing economic conditions provide some explanation for the higher own and cross volatility spillover effects. After Hong Kong returned to mainland China on first July 1997 and joined the World Trade Organization (WTO) at 2001, the economic growth in China increased sharply. Meanwhile, China's financial system deregulation and liberalization attracted more foreign capital inflows increasing globalization.

5.*2 Sample period: 9 August 2007 – April 2011*

Estimates of Eq.(5), stated in Table 4, show that, in contrast to China's equity market, own volatility in USA (A_{11}) and Japan (A_{33}) markets increased considerably. These results are interpretable given the fact that the crisis triggered in the USA economy while Japan's financial market is highly exposed to the USA financial sector. For the cross volatility spillover parameters, we observe that $A_{13} > A_{34} > A_{23} > A_{14} > A_{12} > A_{24}$ showing strong effects for USA-Japan, Japan-China and EMU-Japan. Moreover, although the spillovers of USA-China are high do not appear that influenced by the recent crisis. Some factors worked favourably in keeping the China's equity market relatively stable. Among them are: (a) favourable external position, (b) healthy fiscal position, (c) high amount of domestic savings, and (d) stable banking system.

Also we notice the increased spillover effects of Japan with the other three markets (A_{13}, A_{34}, A_{23}). This seems reasonable given Japan's exposure to USA financial sector. Specifically, according to Nanto (2010), healthy financial positions helped Mitsubishi UFG Group, Japan's largest bank, and Nomura, the country's largest brokerage, to buy pieces of distressed US investment banks as the crisis was deepening in October 2007. Mitsubishi UFG bought twenty one per cent of Morgan Stanley for nine billion USD, and Nomura purchased the Asian, European and Middle Eastern operations of Lehman Brothers. Moreover, the Japanese economy is highly exposed to slowdowns in its export markets, particularly the USA and EMU markets. This can also explain the sharp increase of spillovers effects for Japan-EMU.

5.3 Diagnostic tests and hypothesis testing

Table 5 summarises the results from testing hypothesis. In all cases the null hypothesis of no own or cross spillover effects is rejected at 1% significance level. Moreover the reported Q - test statistics of Ljuing-Box, provide evidence of no serial autocorrelation and therefore no misspecification errors of the estimated diagonal vech model.

6. Conclusions

This paper investigates the volatility spillover effects among equity markets of USA, EMU, China and Japan for the period 1996 – 2011 due to US subprime crisis. A vech representation of MGARCH model has been estimated and tested in order to quantify the volatility spillovers effects.

The empirical results indicate that the Chinese equity market has been affected to a smaller extend from the US subprime crisis compared to the Japanese and EMU equity markets. Moreover, the Japanese market exhibits strong spillovers with China and EMU as a result of the subprime crisis.

Our empirical findings support the conclusion that financial managers from USA and EMU can benefit from diversifying into the Chinese equity market. On the other hand, investment in Japan's equity market seems riskier, after the subprime crisis, given the increased level of spillover effects. Further research could consider the asymmetric effects on conditional variance through, for example, asymmetric generalized dynamic conditional correlation models.

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Table 1: Key annual macroeconomic statistics

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Panel A: USA															
Trade balance	-189.10	-196.49	-246.27	-334.58	-444.31	-419.62	-472.57	-539.05	-662.97	-780.87	-836.66	-820.14	-831.68	-503.58	-643.55
Direct investment abroad	-91.88	-104.82	-142.64	-224.93	-159.21	-142.35	-154.46	-149.56	-316.22	-36.24	-244.92	-414.00	-351.14	-268.68	-345.62
Portfolio investment assets	-149.32	-116.85	-130.20	-122.24	-127.91	-90.64	-48.57	-123.13	-177.36	-257.54	-498.90	-390.75	285.88	-393.47	-144.03
Equity securities assets	-82.71	-57.29	-101.36	-114.31	-106.71	-109.12	-16.95	-118.00	-84.76	-186.69	-137.33	-147.78	39.03	-63.30	-78.60
Debt security assets	-66.61	-59.57	-28.84	-7.93	-21.19	18.48	-31.61	-5.13	-92.61	-70.85	-361.57	-242.96	246.84	-330.17	-65.44
GDP Vol (2005=100)	74.65	77.97	81.37	85.29	88.82	89.78	91.41	93.69	97.04	100.00	102.67	104.67	104.67	101.92	104.83
Unemploement Rate %	5.42	4.90	4.51	4.20	4.00	4.70	5.78	5.99	5.53	5.10	4.62	4.62	5.78	9.27	9.62
Panel B: EMU															
Trade balance	n.a.	n.a.	121.95	78.17	25.86	61.05	116.03	112.94	125.38	65.42	29.32	75.76	-18.91	57.31	32.02
Direct investment abroad	n.a.	n.a.	-195.08	-348.67	-413.35	-297.91	-163.74	-164.69	-215.29	-453.55	-542.69	-706.04	-494.90	-396.72	-110.54
Portfolio investment assets	n.a.	n.a.	-403.37	-341.83	-385.16	-254.77	-163.47	-318.08	-428.80	-514.64	-650.47	-601.34	-17.16	-117.21	-157.50
Equity securities assets	n.a.	n.a.	-129.30	-175.68	-267.61	-90.85	-34.05	-90.34	-132.42	-165.99	-193.24	-86.86	147.86	-71.00	-102.00
Debt security assets	n.a.	n.a.	-274.06	-166.15	-117.55	-163.92	-129.42	-227.74	-296.38	-348.66	-457.23	-514.48	-165.01	-46.21	-55.49
GDP Vol (2005=100)	n.a.	n.a.	86.68	89.34	92.93	94.69	95.59	96.37	98.24	100.00	103.18	106.12	106.46	102.16	103.86
Unemploement Rate %	n.a.	n.a.	n.a.	9.34	8.46	8.03	8.43	8.83	9.02	9.02	8.37	7.51	7.57	9.45	10.00
Panel C: Japan															
Trade balance	83.58	101.60	122.39	123.33	116.72	70.21	93.83	106.40	132.13	93.96	81.30	104.75	38.13	43.63	90.97
Direct investment abroad	-23.45	-26.06	-24.62	-22.27	-31.53	-38.50	-32.02	-28.77	-30.96	-45.44	-50.17	-73.49	-130.82	-74.62	-57.22
Portfolio investment assets	-100.61	-47.06	-95.24	-154.41	-83.36	-106.79	-85.93	-176.29	-173.77	-196.40	-71.04	-123.45	-189.64	-160.25	-262.64
Equity securities assets	-8.17	-13.73	-14.00	-32.40	-19.72	-11.28	-37.28	-4.47	-31.47	-22.97	-25.04	-26.09	-65.56	-29.69	-21.46
Debt security assets	-92.43	-33.34	-81.24	-122.01	-63.64	-95.51	-48.65	-171.82	-142.30	-173.43	-46.00	-97.36	-124.08	-130.56	-241.18
GDP Vol (2005=100)	91.75	93.17	91.16	91.15	93.73	93.88	94.12	95.50	98.10	100.00	102.04	104.39	103.17	96.67	100.52
Unemploement Rate %	3.35	3.40	4.11	4.68	4.72	5.03	5.38	5.26	4.72	4.43	4.14	3.84	3.99	5.07	5.08
Panel D: China															
Trade balance	19,535.00	46,222.00	46,614.00	35,982.00	34,473.70	34,017.00	44,166.60	44,651.60	58,982.30	134,189.00	217,746.00	315,381.00	360,682.00	249,509.00	n.a.
Direct investment abroad	-2,114.00	-2,563.00	-2,634.00	-1,775.00	-916.00	-6,884.00	-2,518.41	152.27	-1,805.05	-11,305.70	-21,160.00	-16,994.90	-53,471.00	-43,898.30	n.a.
Portfolio investment assets	-628.00	-899.00	-3,830.00	-10,535.00	-11,307.50	-20,654.00	-12,094.50	2,983.12	6,486.44	-26,156.90	-110,419.00	-2,324.02	32,749.90	9,887.70	n.a.
Equity securities assets	0.00	0.00	n.a.	n.a.	n.a.	32.00	0.00	0.00	0.00	0.00	-1,454.00	-15,188.60	-1,117.37	-33,815.00	n.a.
Debt security assets	-628.00	-899.00	-3,830.00	-10,535.00	-11,307.50	-20,686.00	-12,094.50	2,983.12	6,486.44	-26,156.90	-108,965.00	12,864.60	33,867.30	43,702.70	n.a.
GDP Vol (2005=100)	45.65	49.90	53.80	57.90	62.79	68.00	74.17	81.61	89.84	100.00	112.68	128.63	141.03	153.88	n.a.
Unemploement Rate %	3.00	3.00	3.10	3.10	3.10	3.60	4.00	4.30	4.20	4.20	4.10	4.00	4.20	4.30	n.a.

Note: Direct Investment Abroad represents the flows of direct investment capital out of the reporting economy and those into the reporting economy, respectively. Direct investment includes equity capital, reinvested earnings, other capital, and financial derivatives associated with various intercompany transactions between affiliated enterprises. Excluded are flows of direct investment capital into the reporting economy for exceptional financing, such as debt-for-equity swaps. Direct investment abroad is usually shown with a negative figure, reflecting an increase in net outward investment by residents, with a corresponding net payment outflow from the reporting economy.

Portfolio Investment Assets includes transactions with non-residents in financial securities of any maturity (such as corporate securities, bonds, notes, and money market instruments) other than those included in direct investment, exceptional financing, and reserve assets.

Table 2: Summary statistics of daily returns of international markets

	USA	EMU	JAPAN	CHINA
Pre crisis				
Mean	8.72E-05	0.000167	1.07E-05	2.63E-05
Median	0.000410	0.000350	-0.000161	-0.000205
Maximum	0.053479	0.054348	0.109175	0.098866
Minimum	-0.075337	-0.057864	-0.070541	-0.130537
Std. Dev.	0.010919	0.010002	0.013212	0.018652
Skewness	-0.227170	-0.222594	0.203966	0.044444
Kurtosis	6.6891	5.132132	6.225434	7.278809
Jarque-Bera	1,698.58***	5,831.38***	1,299.20***	2,251.35***
p-value	(0.0000)	(0.0000)	(0.0000)	(0.0000)
During crisis				
Mean	-6.20E-05	-0.000319	-0.000342	0.000181
Median	0.000514	0.000208	0.000000	0.000155
Maximum	0.109019	0.101241	0.104183	0.157124
Minimum	-0.094087	-0.098206	-0.087861	-0.135215
Std. Dev.	0.017381	0.018807	0.017036	0.026602
Skewness	-0.222718	-0.035154	-0.197545	0.234680
Kurtosis	9.54959	7.13294	7.64432	8.62253
Jarque-Bera	1,718.43***	6,813.10***	8,663.18***	1,269.35***
p-value	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Note: The Jarque-Bera LM statistic is distributed asymptotically as $\chi^2(2)$ under the null hypothesis of normality. *denotes a statistical significance at 10% level, * *denotes a statistical significance at a 5% level, ***denotes statistical significance at 1% level.

Table 3: Estimated coefficient of conditional variance equations, sample period: April 1996 - 9 August, 2007.

Market i	USA (i=1)		EMU (i=2)		Japan (i=3)		China (i=4)	
	coefficient	p-value	coefficient	p-value	coefficient	p-value	coefficient	p-value
C(i,1)	1.01E-09	0.7784						
C(i,2)	4.16E-09	0.6180	1.72E-08	0.2580				
C(i,3)	8.96E-09	0.5828	3.70E-08*	0.0811	7.96E-08*	0.0637		
C(i,4)	6.57E-08	0.5747	2.7E-07**	0.0302	5E-07***	0.0008	4E-06***	0.0000
A(i,1)	0.0263***	0.0000						
A(i,2)	0.0281***	0.0000	0.0300***	0.0000				
A(i,3)	0.0252***	0.0000	0.0269***	0.0000	0.0241***	0.0000		
A(i,4)	0.0427***	0.0000	0.0456***	0.0000	0.0408***	0.0000	0.0691***	0.0000
B(i,1)	0.9760***	0.0000						
B(i,2)	0.9768***	0.0000	0.9732***	0.0000				
B(i,3)	0.9768***	0.0000	0.9755***	0.0000	0.9777***	0.0000		
B(i,4)	0.9468***	0.0000	0.9454***	0.0000	0.9476***	0.0000	0.9184***	0.0000

Note: *denotes statistical significance at 10% level, **denotes statistical significance at 5% level, ***denotes statistical significance at 1% level. The BHHH (Berndt, Hall, Hall and Hausman) algorithm is used to produce the maximum likelihood parameter estimates and their corresponding asymptotic standard errors. Degrees of freedom (t-distribution): 9.083***

Table 4: Estimated coefficient of variance covariance equations, sample period: 9 August, 2007 – April 2011.

Market i	USA (i=1)		EMU (i=2)		Japan (i=3)		China (i=4)	
	coefficient	p-value	coefficient	p-value	coefficient	p-value	coefficient	p-value
C(i,1)	1.44E-10	0.9612						
C(i,2)	-3.03E-09	0.9199	6.37E-08	0.3888				
C(i,3)	-3.60E-08	0.9225	7.57E-07	0.1027	9E-06***	0.0004		
C(i,4)	-6.79E-09	0.9220	1.43E-07	0.1917	1.7E-06**	0.0158	3.20E-07	0.1373
A1(i,1)	0.0466***	0.0000						
A1(i,2)	0.0378***	0.0000	0.0307***	0.0000				
A1(i,3)	0.0543***	0.0000	0.0442***	0.0000	0.0634***	0.0000		
A1(i,4)	0.0418***	0.0000	0.0340***	0.0000	0.0488***	0.0000	0.0376***	0.0000
B1(i,1)	0.9561***	0.0000						
B1(i,2)	0.9636***	0.0000	0.9710***	0.0000				
B1(i,3)	0.9216***	0.0000	0.9286***	0.0000	0.8881***	0.0000		
B1(i,4)	0.9600***	0.0000	0.9600***	0.0000	0.9251***	0.0000	0.9637***	0.0000

Note: Same as Table 2. Degrees of freedom (t-distribution): 8.03***

Table 5: Testing hypotheses of no spillover effects and Ljuing-Box test

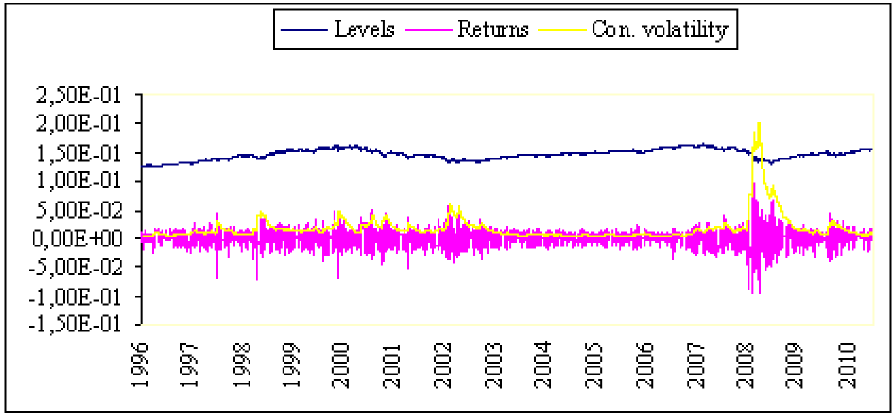
1st set of H_0:	*pre crisis period*				
Wald test:					
H_0:	$a_1 = a_2 = a_3 = a_4 = 0$	$a_1 = 0$	$a_2 = 0$	$a_3 = 0$	$a_4 = 0$
Chi-square:	1,294.83***	421.81***	416.42****	313.62***	426.92***
p-value:	0.0000	0.0000	0.0000	0.0000	0.0000
Deg. of freedom:	4	1	1	1	1
2nd set of H_0:					
H_0:	$b_1 = b_2 = b_3 = b_4 = 0$	$b_1 = 0$	$b_2 = 0$	$b_3 = 0$	$b_4 = 0$
Chi-square:	2,021,432.2***	811,626.1***	667,800.5***	732,095.5***	68,694.9***
p-value:	0.0000	0.0000	0.0000	0.0000	0.0000
Deg. of freedom:	4	1	1	1	1
1st set of H_0:	*during crisis period*				
Wald test					
H_0:	$a_1 = a_2 = a_3 = a_4 = 0$	$a_1 = 0$	$a_2 = 0$	$a_3 = 0$	$a_4 = 0$
Chi-square:	424.77***	221.95***	257.51***	86.33***	164.55***
p-value:	0.0000	0.0000	0.0000	0.0000	0.0000
Deg. of freedom:	4	1	1	1	1
2nd set of H_0:					
H_0:	$b_1 = b_2 = b_3 = b_4 = 0$	$b_1 = 0$	$b_2 = 0$	$b_3 = 0$	$b_4 = 0$
Chi-square:	465,279.2***	149,357.5***	395,284.8***	6,340.5***	157,693.8***
p-value:	0.0000	0.0000	0.0000	0.0000	0.0000
Deg. of freedom:	4	1	1	1	1

	pre crisis period	*during crisis period*
Ljuing-Box test: H_0: no serial auto-corelation		
Q-statistic:	765.70	515.97
Lags:	45	30
p-value:	0.1156	0.1241

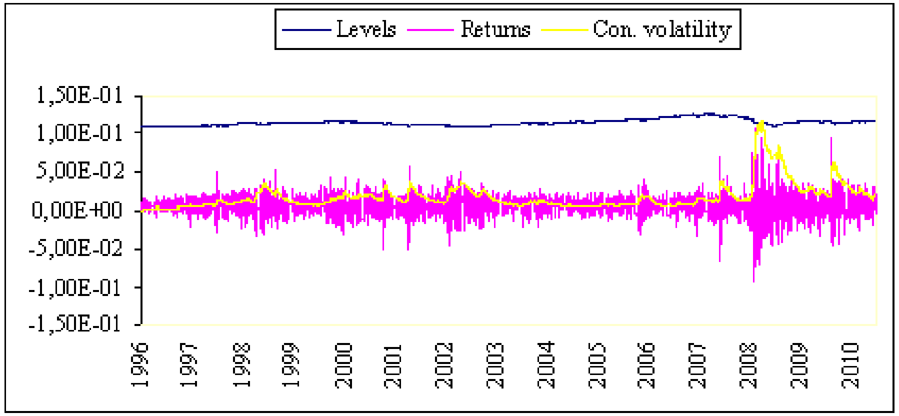
Note: *denotes a statistical significance at 10% level, **denotes a statistical significance at a 5% level, ***denotes statistical significance at 1% level.

Figure 1. Markets Returns, Conditional variance and levels figures

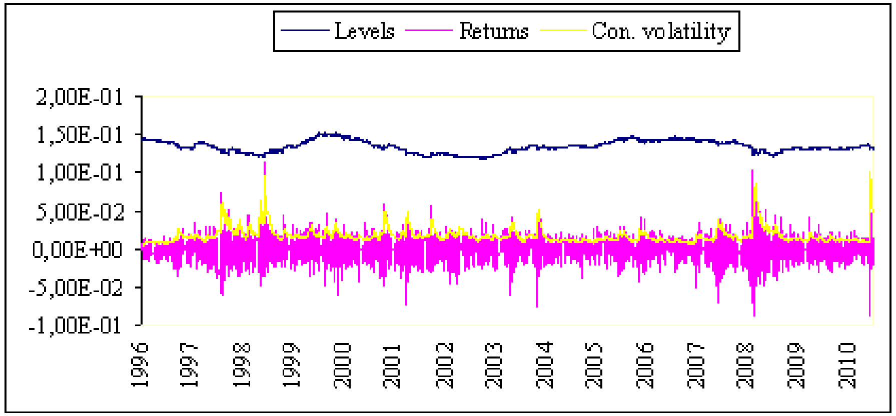
USA



EMU



Japan



China

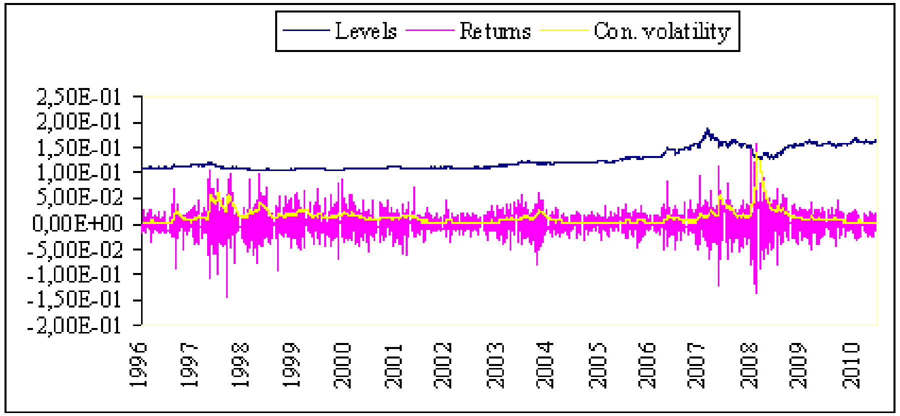
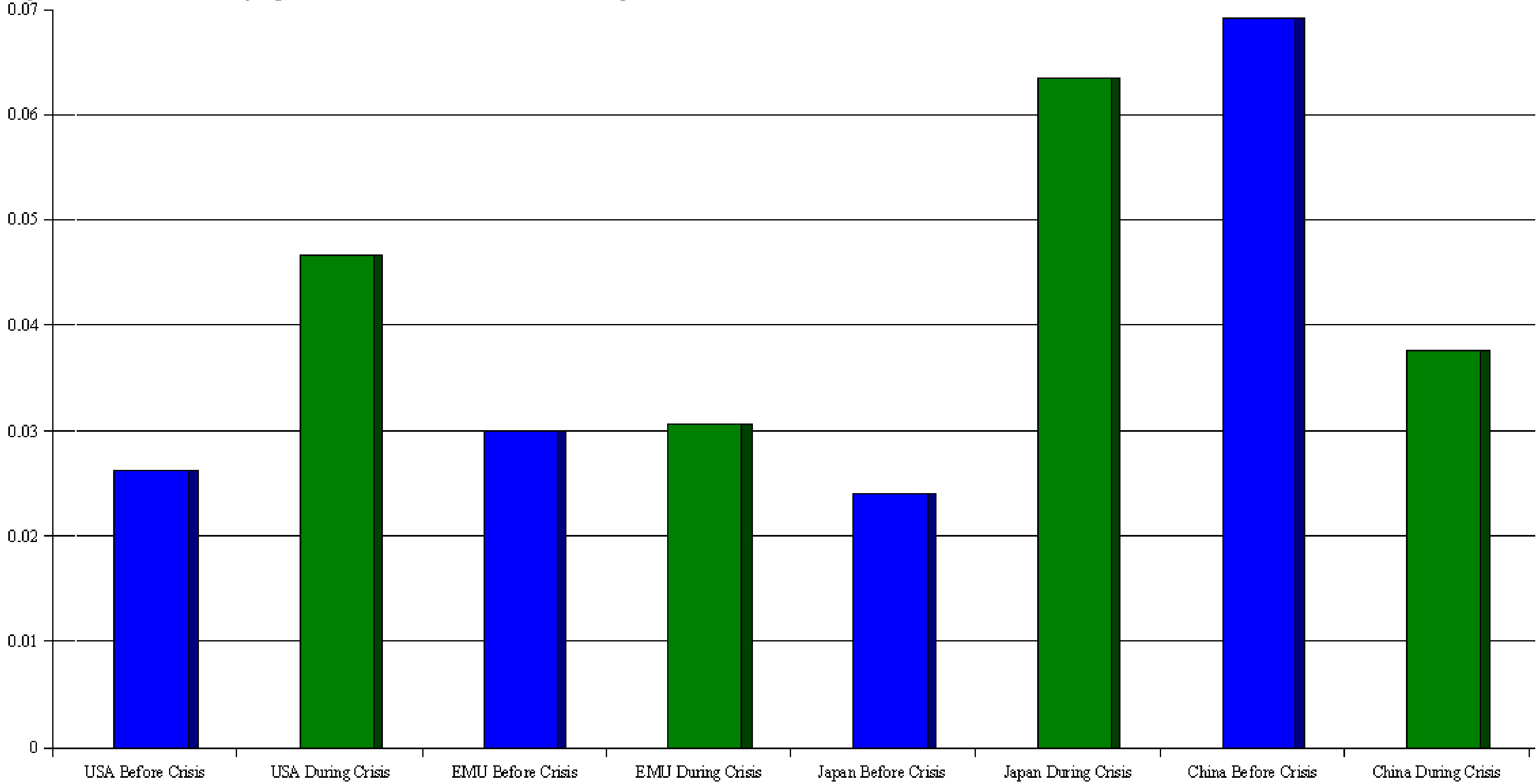
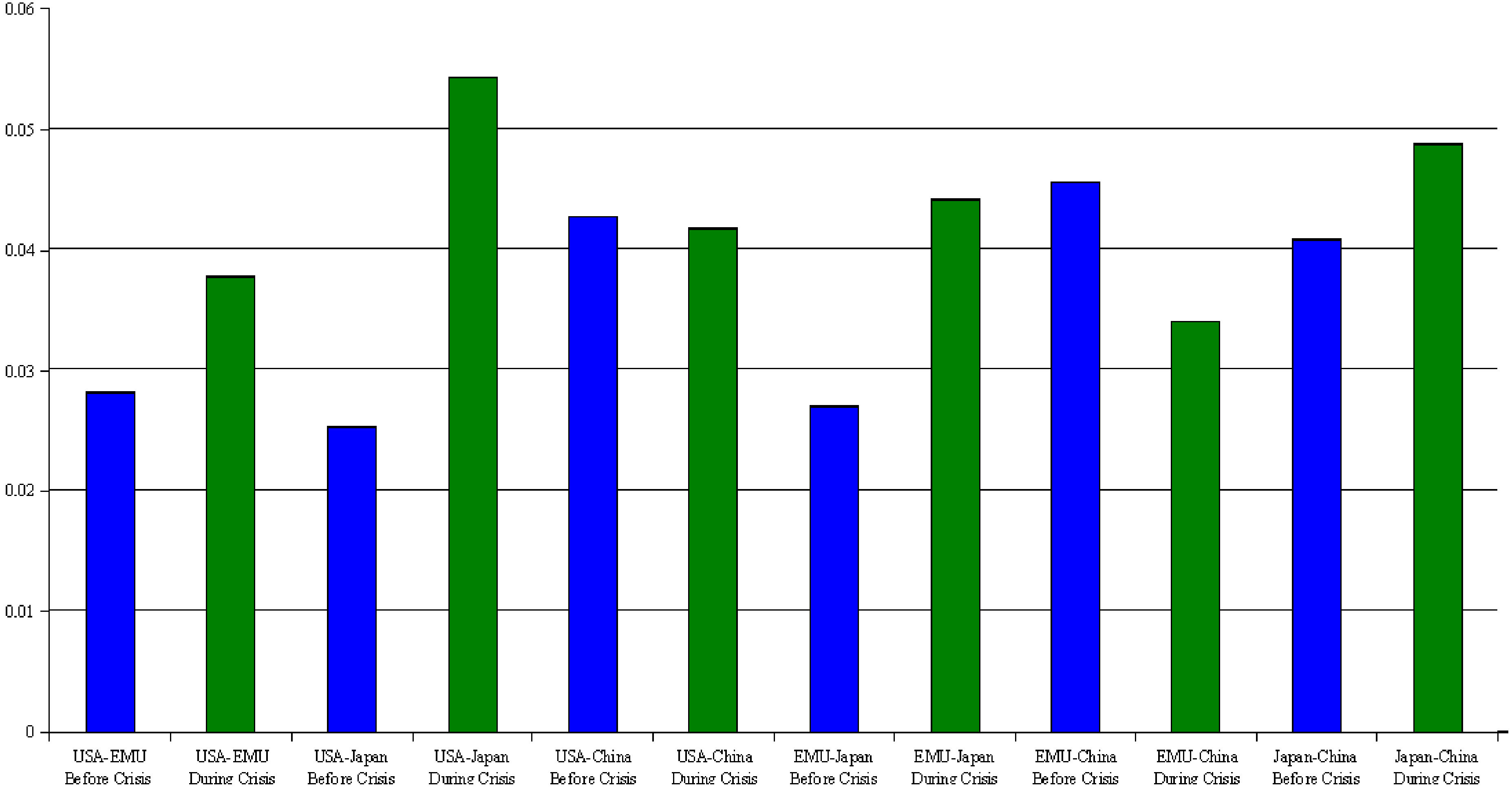


Figure 2. Own volatility spillover effects before and during the crisis



Note. Blue columns indicate before crisis period and green during crisis period.

Figure 3. Cross volatility spillover effects before and during the crisis



Note: Same as Figure 2.