Economic Modelling 29 (2012) 1946–1959

Contents lists available at SciVerse ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

The more contagion effect on emerging markets: The evidence of DCC-GARCH model

Sibel Celık

Dumlupinar University, Turkey

ARTICLE INFO

Article history:
Accepted 9 June 2012

JEL classifications:
F31
G01
G15

Keywords:
Contagion
DCC-GARCH
Financial crisis
Emerging markets

ABSTRACT

The paper aims to test the existence of financial contagion between foreign exchange markets of several emerging and developed countries during the U.S. subprime crisis. As a result of DCC-GARCH analysis, we find the evidence of contagion during U.S. subprime crisis for most of the developed and emerging countries. Another finding is that emerging markets seem to be the most influenced by the contagion effects during U.S. subprime crisis. Since financial contagion is important for monetary policy, risk measurement, asset pricing and portfolio allocation, the findings of paper may be interest of policy makers, investors and portfolio managers.

1. Introduction

During the past years, financial markets have been suffered from U.S. financial crisis triggered by the bursting of the U.S. mortgage bubble. Fig. 1 shows dramatic movements in foreign exchange markets of several developed and emerging countries during the global crisis. While the value of U.S dollar is decreasing, the value of several countries national currency is increasing during crisis period. These cases imply that dramatic movements in one foreign exchange market may have a powerful impact on markets throughout the world. These co-movements of different countries financial markets may arise from contagion or interdependence betweeen financial markets.

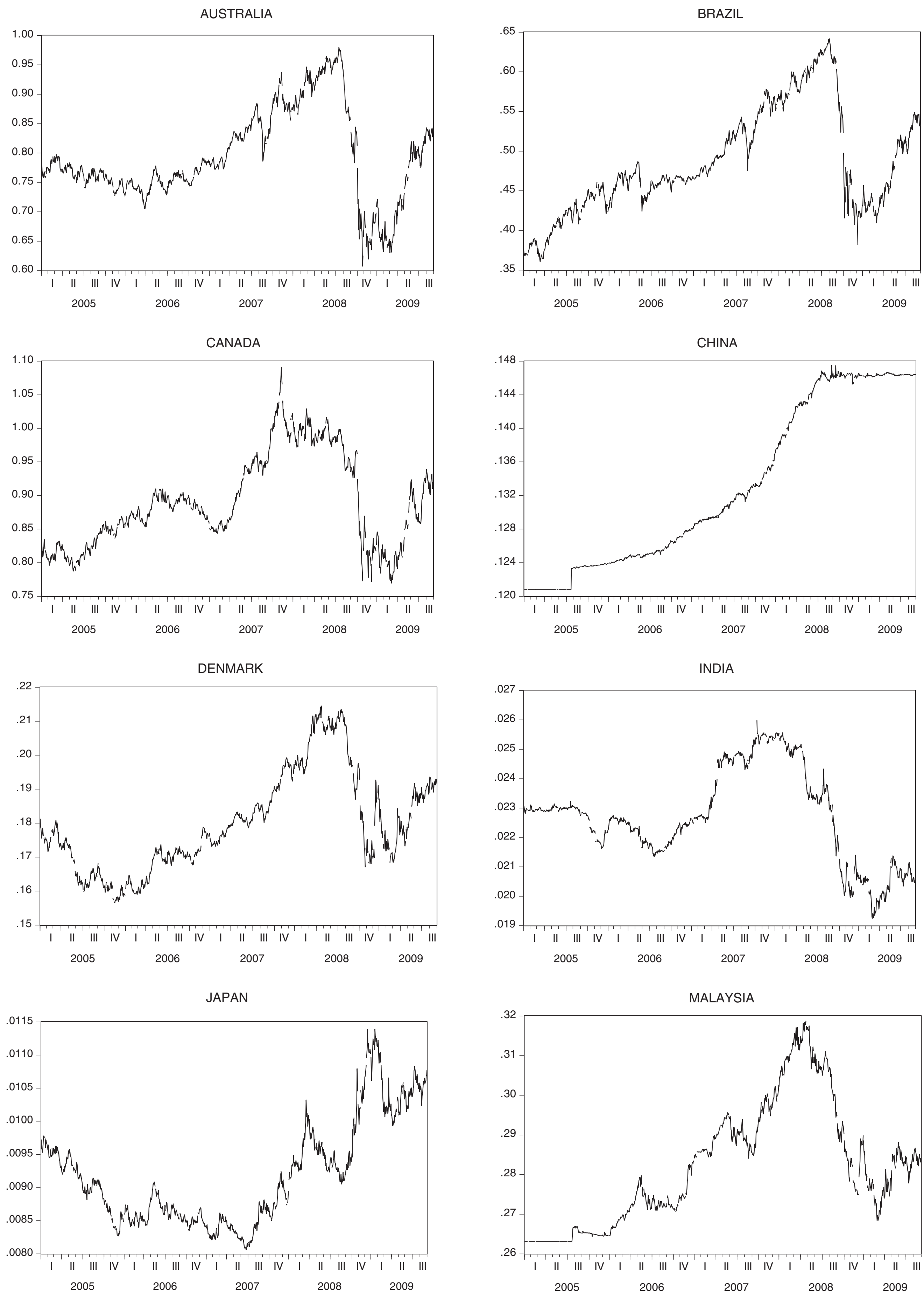
Definition of contagion is one of the most debated topic in the literature. In this paper, contagion is defined as a significant increase in the cross-market correlation during the period of crisis (Forbes and Rigobon, 2002). Therefore, it is necessary to compare the correlation between two financial markets during relatively stable period (pre-crisis) to the during a period of turmoil (crisis period). According to this approach, if two markets are moderately correlated during periods of stability and a shock to one market leads to a significant increase in market co-movement, this would generate contagion. However, if two markets are traditionally highly correlated, even if they continue to be highly correlated after a shock to one market, this may not generate contagion. In other words, it is only contagion if the cross-market correlation increases significantly in crisis period. If the correlation does not increase significantly, this co-movement between financial markets is called interdependence which refers to strong real linkages between two economies (Forbes and Rigobon, 2002).

The pattern and severity of of financial contagion depend on markets' sensivities to shared macroeconomic risk factors, and on the amount of information asymmetry in each market (Kodres and Pritsker, 2002). Countries do not need to be linked directly by macroeconomic fundementals in order to transmit shocks. All that is required for transmission of shocks is for macroeconomic variables to be shared indirectly through other countries. Another conclusion from contagion is that information asymmetries increase the effect of contagion. The effect of contagion on asset prices are greater in markets with greater information asymmetries. Large fluctuations in asset prices is experienced in countries with high level of asymmetris information, whereas countries with low levels of asymmetric information do not. Because, emerging markets have higher levels of asymmetric information than do developed markets, it is expected that emerging markets are influenced much more severely by contagion than developed markets (Lhost, 2004).

The issue of contagion in financial markets is of fundamental importance because of its important consequences for the global economy in relation to monetary policy, optimal asset allocation, risk measurement, capital adequacy and asset pricing. Recent important papers focus on contagion includes Longstaff (2010), Aloui et al. (2011) and many others. While some papers focus on history of financial crisis and crisis models (Bordo and Eichengreen, 1999; Kaminsky and Reinhart, 1999), papers focus on theoratical models on contagion also participate in the literature (Calvo and Mendoza, 2000; Kodres and Pritsker, 2002). In the literature, studies mostly concentrate on empirical application of contagion tests. (Bae et al., 2003; Bekaert et al.,

E-mail address: sibelcelik1@gmail.com.

0264-9993/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.econmod.2012.06.011


AUSTRALIA
1.00 0.95 0.90 0.85 0.80 0.75 0.70 0.65 0.60
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
BRAZIL
.65 .60 .55 .50 .45 .40 .35
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
CANADA
1.10 1.05 1.00 0.95 0.90 0.85 0.80 0.75
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
CHINA
.148 .144 .140 .136 .132 .128 .124 .120
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
DENMARK
.22 .21 .20 .19 .18 .17 .16 .15
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
INDIA
.027 .026 .025 .024 .023 .022 .021 .020 .019
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
JAPAN
.0115 .0110 .0105 .0100 .0095 .0090 .0085 .0080
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009
MALAYSIA
.32 .31 .30 .29 .28 .27 .26
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009


MEXICO
NEW ZEALAND
NORWAY
SINGAPORE
SOUTH AFRICA
SOUTH KOREA
SWEDEN
SWITZERLAND

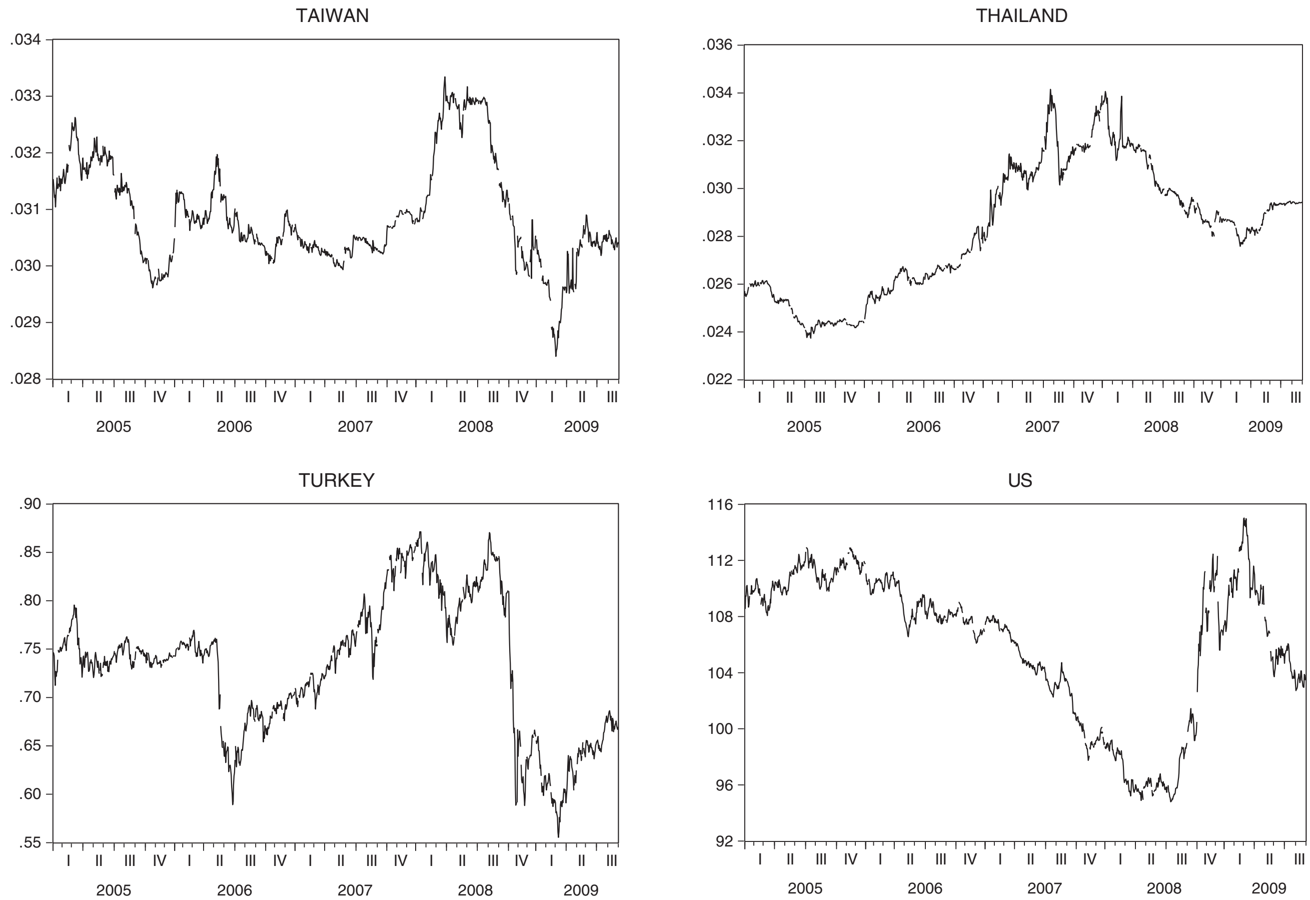


Fig. 1. Foreign exchange rate price series.

2005; Corsetti et al., 2002; Eichengreen et al., 1995, 1996; Favero and Giavazzi, 2002; Forbes and Rigobon, 2002).

In the literature, some papers test the existence of contagion of various crisis on different financial markets [*Stock Markets*: (Bouaziz et al., 2012; Chiang et al., 2007; Cho and Parhizgari, 2008; Khan and Park, 2009); *Foreign Exchange Markets:* (Dungey et al., 2004; Horen et al., 2006; Tai, 2007), *Bond Markets:* (Dungey et al., 2006; Ismailescu and Kazemi, 2008); *Future Markets:* (Tai, 2003); *Credit Default Swap Markets* (Coudert and Gex, 2008; Jorion and Zhang, 2007)], some examine the transfer mechanism of these crises from one country to another. They try to explain the contagion effect through trade linkages between countries (Glick and Rose, 1999) or through transnational financial linkages (Van Rijckeghem and Weder, 2001).

In addition to papers related to contagion impact of earlier crisis, studies on recent Global Crisis also take part in literature. For example, Longstaff (2010) studies the contagion effects of CDO market on stock exchange markets and bond markets. Longstaff (2010) uses data of ABX index, 1 and 10 year maturity bond yields, and U.S. stock index returns. Longstaff (2010) observes important findings concerning contagion in financial markets and concludes that contagion effects spread first from lower-rated ABX indexes to higher-rated ABX indexes, and then from the subprime markets to the Treasury bond and stock markets.

Horta et al. (2008) analyse contagion impact of American subprime mortgage crisis on Canadian, Japanese, Italian, France, UK, German and Portuguese stock exchnage markets by using copula models. As a result, while Horta et al. (2008) confirm remarkable contagion impact for Canada, Japan, Italy, France and UK, for Germany this impact is not significant as other countries. The most contagion impact is observed in Canada.

Dungey (2009) examines contagion between U.S, U.K. , Europen, Japanese and Australian money markets and stock exchange markets during the credit crunch period. The findings of Dungey (2009) can be summarized as follows: volatility in global shocks are transmitted to all markets in the same manner as during the non-crisis period. The contribution of contagion to volatility in the non-U.S. markets is in line with results found for the contribution of contagion in evidence get for previous crises. The U.S. equity market seems to have a role in absorbing shocks from the U.S. money market and acts as the distributor of these shocks to other markets.

Naoui et al. (2010) test the existence of contagion phenomenon following the U.S. subprime crisis for six developed and ten emerging stock markets by applying Dynamic Conditional Correlation Model. They conclude that contagion is strong between U.S. and the develeoped and emerging countries during the subprime crisis.

Hwang et al. (2010) examine the contagion effects of the U.S. subprime crisis on international stock markets using a DCC-GARCH model on 38 country data. In conclusion, they find evidence of financial contagion not only in emerging markets but also in developed markets during the U.S. subprime crisis.

Bouaziz et al. (2012) test the contagion effect of the U.S. stock market on the stock markets of developed countries during the subprime financial crisis (2007–2008) by using DCC-GARCH model. As a result of DCC-GARCH model, they find that correlations between markets have significantly increased during the U.S. subprime crisis period and conclude that the crisis has spread across different markets, which is a clear evidence of contagion.

The literature on contagion of financial crisis seems to be focused on mostly stock exchange markets. This paper aims to test the existence of financial contagion between foreign exchange markets during the U.S. subprime crisis. This paper makes several important contributions to the recent literature on financial contagion. First, this paper tests the existence of contagion between foreign exchange markets different from the existence literature which largely focus on testing contagion between stock markets. Focusing on foreign exchange markets provides to reduce the problems arising from different time zones of the markets because foreign exchange markets are the most liquid financial market in the world and foreign exchange trading takes place around the world 24 h a day. Second, the paper aims to answer the question of whether emerging markets are more vulnerable to financial crisis than developed markets during the analysed period.

The paper is organized as follows. Section 2 defines the dataset. Section 3 describes the methodology used. Section 4 presents and discusses the empirical findings. Section 5 summarizes and concludes.

2. Data

We examine the contagion effect between foreign exchange markets of U.S. and emerging and developed markets during the Global Financial Crisis. The dataset includes daily US dollar per local currencies of Australia, Brazil, Canada, China, Denmark, India, Japan, Malaysia, Mexico, New Zealand, Norway, Singapore, South Africa, South Korea, Sweden, Switzerland, Taiwan, Thailand and Turkey. We use trade-weighted value index of the US dollar as a proxy for exchange value of dollar. The sample period runs from 03/01/2005 to 31/08/2009. The data is obtained from Board of Governors of the Federal Reserve System except US dollar per Turkish Lira. The data for US dollar per Turkish Lira is obtained from Central Bank of the Republic of Turkey.

We calculate foreign exchange rate returns as $\ln\left(\frac{P_t}{P_{t-1}}\right)$ where P_t is the price level of for the foreign exchange market at time t.

In the literature, determination of crisis period is a very difficult decision (Kaminsky and Schmukler, 1999). In this study, we prefer to consider news based data for identifying crisis period. In the existing literature, we observe that Global Financial Crisis gives the first signal on 17 July 2007. 17 July 2007 is announcement day of problems related to Bear Stearns hedge funds. In the literature, there are studies that use this date as a starting date of crisis (Dungey, 2009). As a result, we use 17 July 2007 as starting point of crisis period. While pre-crisis period covers data from 03/01/2005 through 16/07/2007, crisis period covers from 17/07/2007 through 31/08/2009.

In this study, only the data for foreign exchange markets are used for the period 03.01.2005 to 31.08. 2009. So the results may not generalize in other asset markets.

3. Methodology

3.1. DCC-GARCH model

We apply DCC-GARCH model of Engle (2002) to test the existence of contagion during Global Financial Crisis. A major advantage of using this model is the detection of possible changes in conditional correlations over time, which allows us to detect dynamic investor behavior in response to news and innovations. Moreover, the dynamic conditional correlations measure is appropriate to investigate possible contagion effects due to herding behavior in emerging financial markets during crises periods [see Corsetti et al. (2005), Boyer et al. (2006), Chiang et al. (2007) and Syllignakis and Kouretas (2011)]. Another advantage of DCC-GARCH model is that DCC-GARCH model estimates correlation coefficients of the standardized residuals and so accounts for heteroscedasticity directly (Chiang et al., 2007). Since the volatility is adjusted by the procedure, the time varying correlation (DCC) does not have any bias from volatility. Unlike the volatility-adjusted cross-market correlations employed in Forbes and Rigobon (2002), DCC-GARCH continuously adjusts the correlation for the time-varying volatility. Hence, DCC provides a superiour measure for correlation (Cho and Parhizgari, 2008).

The estimation of Engle's DCC-GARCH model comprises two steps: the first is the estimation of the univariate GARCH model, the second is estimation of the conditional correlations that vary through time.

The multivariate DCC-GARCH model is defined as follows;

$$X_t = \mu_t + H_t^{1/2}\varepsilon_t \tag{1}$$

$$\begin{cases} H_t = D_t R_t D_t \\ R_t = (diag(Q_t))^{-1/2} Q_t (diag(Q_t))^{-1/2} \\ D_t = diag\left(\sqrt{h_{11,t}}, \sqrt{h_{22,t}}, \ldots\ldots, \sqrt{h_{NN,t}}\right) \end{cases} \tag{2}$$

where $X_t = (X_{1t}, X_{2t}, \ldots. X_{Nt})$ is the vector of the past observations, H_t is the multivariate conditional variance, $\mu_t = (\mu_{1t}, \mu_{2t}, \ldots. \mu_{Nt})$ is the vector of conditional returns, $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t}, \ldots\ \varepsilon_{Nt})$ is the vector of the standardized residuals, R_t is a $N \times N$ symmetric dynamic correlations

Table 1
Descriptive statistics of foreign exchange rate returns.

Pre-crisis period (03.01.2005–16.07.2007)								
	Mean	Minimum	Maximum	Standard deviation	Skewness	Kurtosis	Jarque–Bera	LB (10)
Australia	0.0001	−0.0218	0.0183	0.0054	−0.3279	3.4724	16.8552***	9.8719
Brazil	0.0005	−0.0453	0.0237	0.0082	−0.8821	6.2973	360.6923***	14.7770
Canada	0.0002	−0.0151	0.0145	0.0046	−0.0023	3.2220	1.2723	16.263*
China	0.0001	−0.0028	0.0201	0.0010	12.0861	235.4287	1,408,416.0***	4.8635
Denmark	0.0000	−0.0227	0.0191	0.0048	−0.1384	4.3766	50.8558***	3.3185
India	0.0001	−0.0155	0.0230	0.0031	0.4850	10.5421	1491.413***	9.6431
Japan	−0.0002	−0.0144	0.0278	0.0052	0.6927	5.3264	189.1049***	3.7910
Malaysia	0.0001	−0.0080	0.0103	0.0019	0.1722	8.7831	865.6474***	28.104***
Mexico	0.0001	−0.0171	0.0118	0.0040	−0.3086	3.4437	14.9044***	16.315*
NewZealand	0.0001	−0.0268	0.0243	0.0066	−0.2578	3.9028	27.8806***	5.5167
Norway	0.0001	−0.0223	0.0198	0.0061	−0.1273	3.7326	15.5189***	7.5579
Singapore	0.0001	−0.0088	0.0212	0.0025	0.7462	10.4559	1491.226***	10.2900
South Africa	−0.0003	−0.0378	0.0302	0.0092	−0.4373	4.2722	61.4793***	8.8208
South Korea	0.0001	−0.0163	0.0188	0.0039	0.2197	4.9832	106.4287***	12.5280
Sweden	0.0000	−0.0203	0.0218	0.0059	0.0668	3.6272	10.6103***	5.0756
Switzerland	−0.0001	−0.0232	0.0196	0.0055	0.1680	3.9099	24.2678***	4.4756
Taiwan	−0.0001	−0.0102	0.0110	0.0030	0.1215	4.4803	58.0470***	9.8528
Thailand	0.0004	−0.0246	0.0323	0.0052	0.7658	9.0463	1003.421***	8.1030
Turkey	0.0001	−0.0477	0.0277	0.0082	−1.0460	7.7373	691.7249***	6.9396
U.S.	−0.0001	−0.0093	0.0083	0.0024	0.1500	3.7276	15.9797***	10.1610

Note: table shows the descriptive statistics for pre-crisis period (03.01.2005–16.07.2007). LB (10) is Ljung-Box Q test statistics for 10 lags. ***, ** and * indicate the significance level at 1%, 5%, 10% respectively.

Table 2
Descriptive statistics of foreign exchange rate returns.

Crisis period (17.07.2007–31.08.2009)								
	Mean	Minimum	Maximum	Standard deviation	Skewness	Kurtosis	Jarque–Bera	LB (10)
Australia	−0.0001	−0.0821	0.0770	0.0148	−0.6770	10.4999	1251.205***	24.904***
Brazil	0.0000	−0.0755	0.0966	0.0158	0.3571	12.2762	1864.626***	41.065***
Canada	−0.0001	−0.0398	0.0566	0.0099	0.3394	7.5624	458.3384***	16.080*
China	0.0001	−0.0098	0.0099	0.0014	0.1134	17.2792	4393.393***	48.240***
Denmark	0.0001	−0.0400	0.0540	0.0088	0.6059	8.5910	705.0287***	14.6510
India	−0.0003	−0.0393	0.0371	0.0069	−0.0033	9.0747	794.9413***	16.602*
Japan	0.0005	−0.0270	0.0521	0.0092	0.7046	6.6342	327.3076***	21.503**
Malaysia	0.0000	−0.0123	0.0194	0.0045	0.3386	4.1922	40.5065***	4.3222
Mexico	−0.0004	−0.0811	0.0596	0.0102	−0.7900	16.2085	3812.048***	15.3230
NewZealand	−0.0002	−0.0617	0.0612	0.0138	−0.2443	6.2507	232.7831***	15.6700
Norway	−0.0001	−0.0431	0.0644	0.0124	0.2493	6.0137	201.0079***	25.731***
Singapore	0.0001	−0.0177	0.0239	0.0045	0.3271	6.9875	351.7481***	16.087*
South Africa	−0.0002	−0.0792	0.0542	0.0147	−0.3607	6.0305	209.0535***	19.074**
South Korea	−0.0005	−0.1013	0.1604	0.0153	1.8081	33.3877	20,173.63***	26.471***
Sweden	−0.0001	−0.0547	0.0530	0.0121	0.3509	5.9811	202.0565***	13.9390
Switzerland	0.0002	−0.0360	0.0497	0.0090	0.3707	6.7933	321.8172***	28.433***
Taiwan	0.0000	−0.0248	0.0342	0.0041	1.2797	19.6586	6119.122***	9.4881
Thailand	−0.0002	−0.0447	0.0352	0.0056	−0.7461	14.9055	3101.321***	20.238**
Turkey	−0.0003	−0.0704	0.1193	0.0131	0.6782	18.1990	5015.983***	14.3470
U.S.	0.0000	−0.0292	0.0209	0.0048	−0.7223	9.5278	962.8948***	14.5030

Note: table shows the descriptive statistics for crisis period (17.07.2007–31.08.2009). LB (10) is Ljung-Box Q test statistics for 10 lags. ***, ** and * indicate the significance level at 1%, 5%, 10% respectively.

matrix and D_t is a diagonal matrix of conditional standard deviations for return series, obtained from estimating a univariate GARCH model with $\sqrt{h_{ii,t}}$ on th ith diagonal, $i=1,2,\ldots.N$.

The DCC specification is defined as follows;

$$
\begin{aligned}
Q_t &= (1-\psi-\zeta)\bar{Q} + \zeta Q_{t-1} + \psi\delta_{i,t-1}\delta_{j,t-1} \\
R_t &= Q_t^{*-1} Q_t Q_t^{*-1}
\end{aligned} \tag{3}
$$

where $(Q_t)=\lfloor q_{ij,t}\rfloor$ is $(N\times N)$ time varying covariance matrix of standardized residuals $\left(\delta_{it}=\frac{\varepsilon_{it}}{\sqrt{h_{it}}}\right)$, $\bar{Q}$ is the unconditional correlations of $\delta_{i,t}\delta_{j,t}$ and $\psi\, and\, \zeta$ are nonnegative scalar parameters that satisfies $\psi+\zeta\langle 1.Q_t^{\,*}=\left[q^{*}{}_{ii,t}\right]=\sqrt{q_{ii,t}}$ is a diagonal matrix with the square root of the i^{th} diagonal element of Q_t on its i^{th} diagonal position.

Therefore, for a pair of markets $i\, and\, j$ their conditional correlation at time t can be defined as:

$$
\rho_{ij,t} = \frac{(1-\psi-\zeta)\bar{q}_{ij} + \psi\delta_{i,t-1}\delta_{j,t-1} + \zeta q_{ij,t-1}}{\left[(1-\psi-\zeta)\bar{q}_{ii} + \psi\delta^2{}_{i,t-1} + \zeta q_{ii,t-1}\right]^{1/2}\left[(1-\psi-\zeta)\bar{q}_{jj} + \psi\delta^2{}_{j,t-1} + \zeta q_{jj,t-1}\right]^{1/2}} \tag{4}
$$

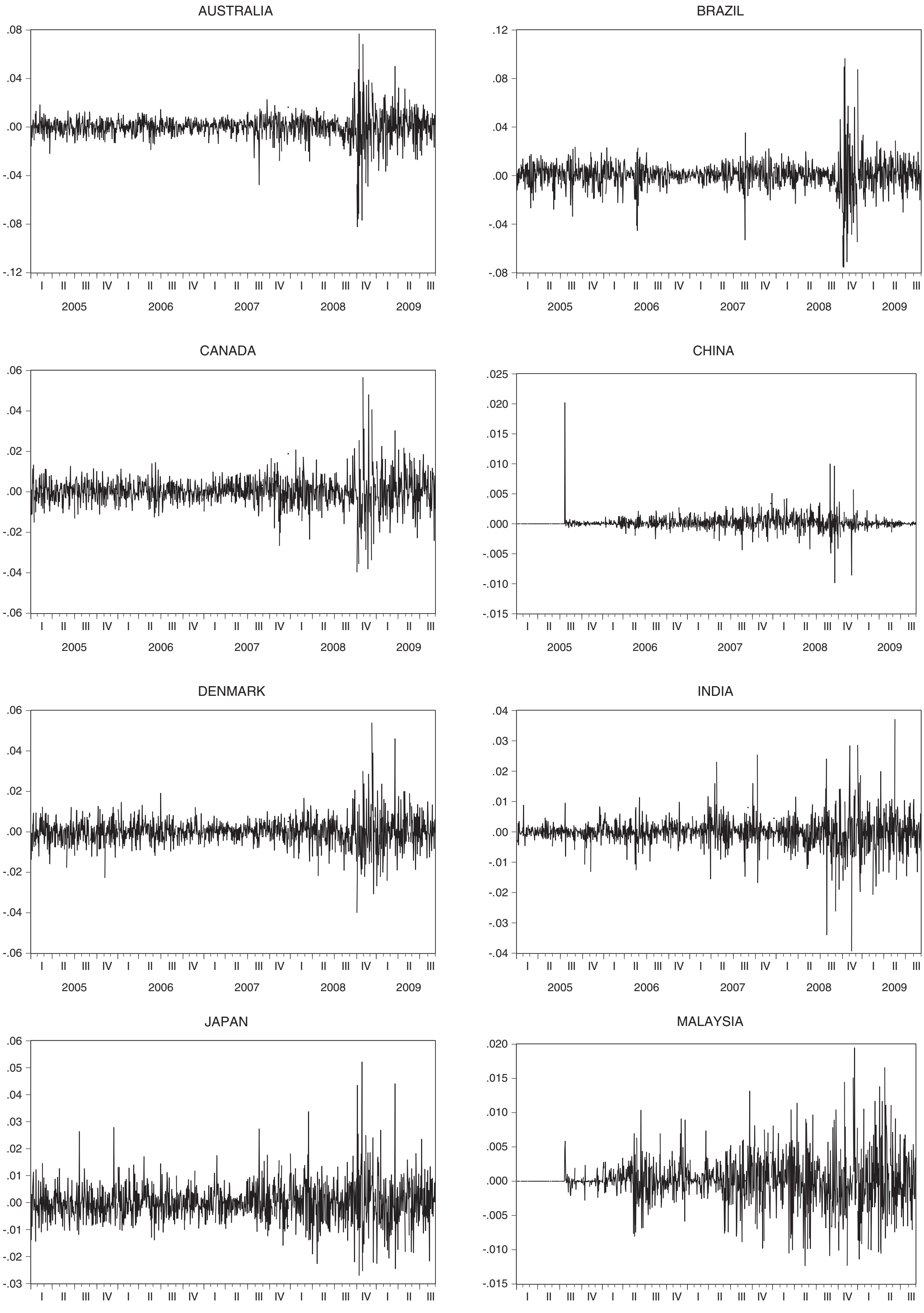
where q_{ij} is the element on the i^{th} line and j^{th} column of the matrix Q_t. The parameters are estimated using quasi-maximum likelihood method (QMLE) introduced by Bollerslev et al. (1992). Under the Gaussian assumption, the log-likelihood of the estimators is;

$$
\begin{aligned}
L(\vartheta) = -\frac{1}{2}\sum_{t=1}^{T} \Big[& \left(n\log(2\pi) + \log|D_t|^2 + \varepsilon_t' D_t^{-1} D_t^{-1}\varepsilon_t\right) \\
& + \left(\log|R_t| + \delta_t' R_t^{-1}\delta_t - \delta_t'\delta_t\right)\Big]
\end{aligned} \tag{5}
$$

Table 3
Descriptive statistics of foreign exchange rate returns.

Entire period (03.01.2005–31.08.2009)								
	Mean	Minimum	Maximum	Standard deviation	Skewness	Kurtosis	Jarque–Bera	LB (10)
Australia	0.0001	−0.0821	0.0770	0.0107	−0.8522	17.2411	9745.803***	45.535***
Brazil	0.0003	−0.0755	0.0966	0.0123	0.1618	16.0853	8116.811***	49.169***
Canada	0.0001	−0.0398	0.0566	0.0075	0.3082	10.6087	2760.681***	21.731**
China	0.0001	−0.0098	0.0201	0.0012	3.8528	75.1014	249,097.5***	43.814***
Denmark	0.0001	−0.0400	0.0540	0.0069	0.5472	10.8027	2941.104***	19.917**
India	−0.0001	−0.0393	0.0371	0.0052	−0.0400	13.4167	5140.905***	23.439***
Japan	0.0001	−0.0270	0.0521	0.0073	0.8637	8.4440	1545.446***	24.347***
Malaysia	0.0001	−0.0123	0.0194	0.0034	0.3264	6.7014	669.2774***	5.9536
Mexico	−0.0001	−0.0811	0.0596	0.0075	−1.0025	25.4299	24,024.94***	24.580***
NewZealand	0.0000	−0.0617	0.0612	0.0105	−0.3272	8.7861	1606.367***	24.248***
Norway	0.0000	−0.0431	0.0644	0.0095	0.2111	8.1856	1282.393***	33.223***
Singapore	0.0001	−0.0177	0.0239	0.0035	0.4410	9.4795	2025.891***	23.744***
South Africa	−0.0002	−0.0792	0.0542	0.0120	−0.3998	6.9058	753.0289***	20.467**
South Korea	−0.0001	−0.1013	0.1604	0.0107	2.2831	62.3468	167,844.9***	50.731***
Sweden	−0.0001	−0.0547	0.0530	0.0093	0.3513	8.2387	1323.580***	18.089*
Switzerland	0.0001	−0.0360	0.0497	0.0073	0.3854	7.8124	1125.347***	37.438***
Taiwan	0.0000	−0.0248	0.0342	0.0035	0.9602	17.5752	10,238.99***	12.724
Thailand	0.0001	−0.0447	0.0352	0.0054	−0.0162	12.2977	4095.503***	21.539**
Turkey	−0.0001	−0.0704	0.1193	0.0107	0.2799	19.8520	13,468.87***	14.5610
U.S.	0.0000	−0.0292	0.0209	0.0037	−0.6748	12.7547	4594.280***	22.962**

Note: table shows the descriptive statistics for crisis period (03.01.2005–31.08.2009). LB (10) is Ljung-Box Q test statistics for 10 lags. ***, ** and * indicate the significance level at 1%, 5%, 10% respectively.


AUSTRALIA
.08
.04
.00
-.04
-.08
-.12
BRAZIL
.12
.08
.04
.00
-.04
-.08
CANADA
.06
.04
.02
.00
-.02
-.04
-.06
CHINA
.025
.020
.015
.010
.005
.000
-.005
-.010
-.015
DENMARK
.06
.04
.02
.00
-.02
-.04
-.06
INDIA
.04
.03
.02
.01
.00
-.01
-.02
-.03
-.04
JAPAN
.06
.05
.04
.03
.02
.01
.00
-.01
-.02
-.03
MALAYSIA
.020
.015
.010
.005
.000
-.005
-.010
-.015
I II III IV I II III IV I II III IV I II III IV I II III
2005 2006 2007 2008 2009

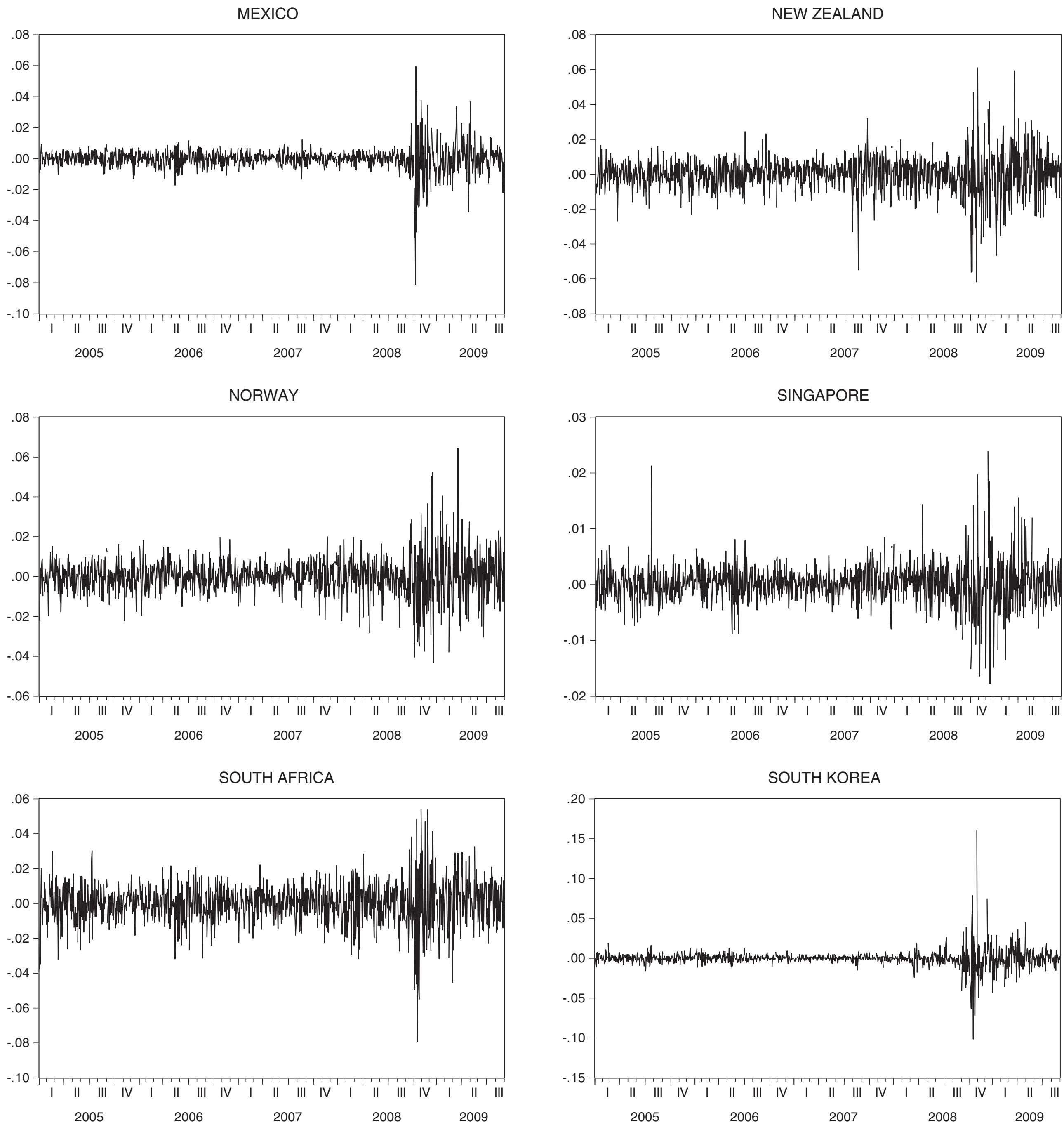


Fig. 2. Foreign exchange rate return series.

where n is the number of equations, T is the number of observations, ϑ is the vector of parameters to be estimated.

3.2. Contagion effect test with dynamic conditional correlation coefficient

We use t-statistics to test consistency of dynamic correlation coefficients between foreign exchange markets in the pre-crisis and crisis periods to judge the contagion effect. We define null and alternative hypotheses as:

$$H_0 = \mu_\rho^{\ crisis} = \mu_\rho^{\ pre-crisis}, \quad H_1 = \mu_\rho^{\ crisis} \neq \mu_\rho^{\ pre-crisis} \tag{6}$$

where $\mu_\rho^{pre-crisis}$ and μ_ρ^{crisis} are the conditional correlation coefficient means of population in the pre-crisis and crisis periods. If the sample sizes are n^{crisis} and $n^{pre-crisis}$, the population variances σ^2_{crisis} and $\sigma^2_{pre-crisis}$ are different and unknown. If the means of dynamic correlation coefficients estimated by DCC are $\bar{\rho}_{ij}^{\ crisis}$ and $\bar{\rho}_{ij}^{\ pre-crisis}$ and the variances are s^2_{crisis} and $s^2_{pre-crisis}$, the t-statistic is calculated as:

$$t = \frac{\left(\bar{\rho}_{ij}^{\ crisis} - \bar{\rho}_{ij}^{\ pre-crisis}\right) - \left(\mu_\rho^{\ crisis} - \mu_\rho^{\ pre-crisis}\right)}{\sqrt{\frac{s^2_{crisis}}{n^{crisis}} + \frac{s^2_{pre-crisis}}{n^{pre-crisis}}}} \tag{7}$$

where $s^2_{crisis} = \frac{1}{n^{crisis}-1} \sum_{t=1}^{n^{crisis}} \left(\rho_{ij}^{\ crisis} - \bar{\rho}_{ij}^{\ crisis}\right)^2$, $s^2_{pre-crisis} = \frac{1}{n^{pre-crisis}-1} \sum_{t=1}^{n^{re-crisis}} \left(\rho_{ij}^{\ pre-crisis} - \bar{\rho}_{ij}^{\ pre-crisis}\right)^2$ the degree of freedom v is;

$$v = \frac{\left(\frac{s^2_{crisis}}{n^{crisis}} + \frac{s^2_{pre-crisis}}{n^{pre-crisis}}\right)^2}{\frac{\left(s^2_{crisis}/n^{crisis}\right)^2}{n^{crisis}-1} + \frac{\left(s^2_{pre-crisis}/n^{pre-crisis}\right)^2}{n^{pre-crisis}-1}}. \tag{8}$$

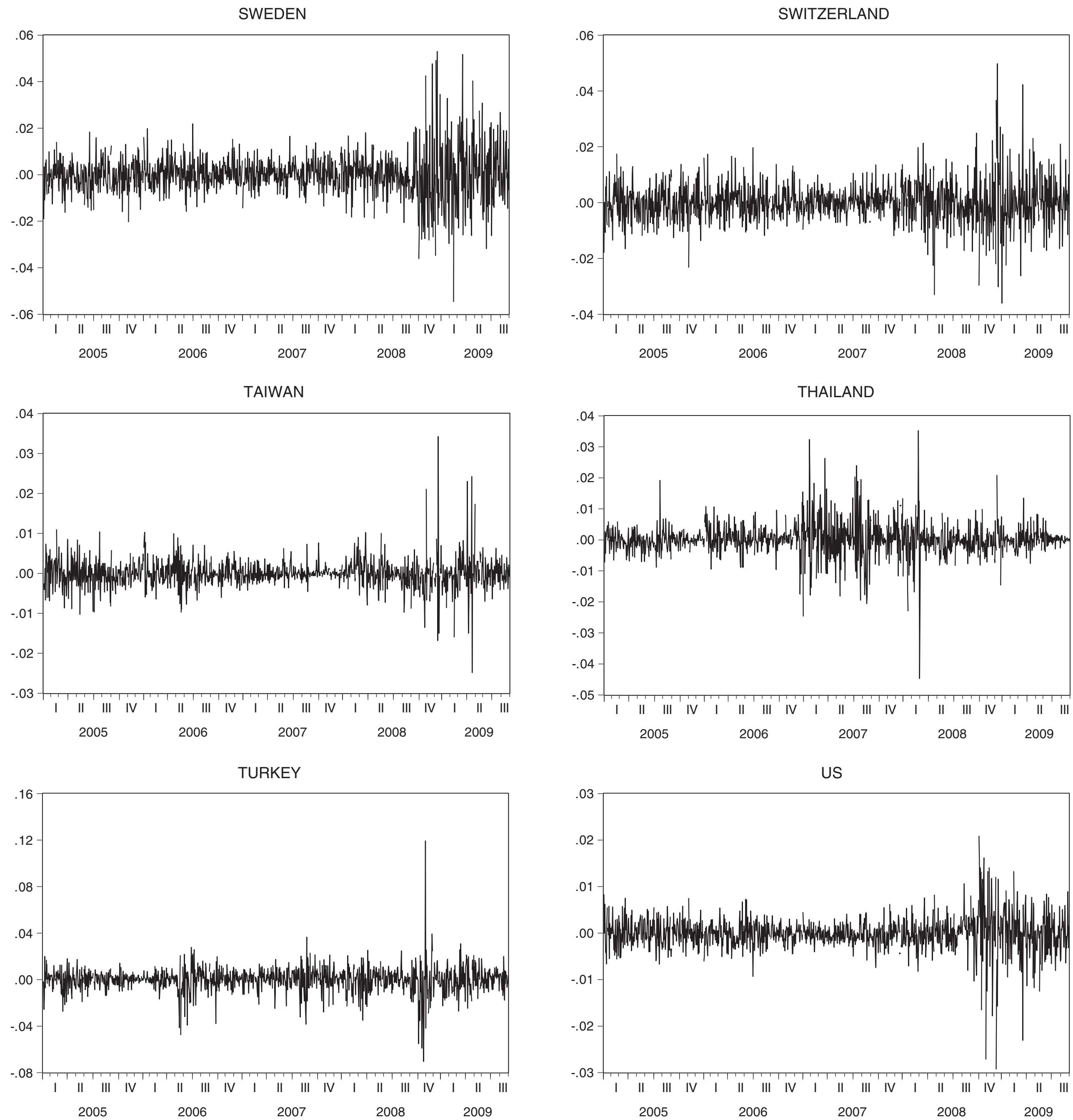


Fig. 2 (*continued*).

If t-statistics is significantly greater than the critical value, H_0 is rejected supporting the existence of contagion effect.

4. Empirical findings

Tables 1, 2 and 3 show the descriptive statistics of foreign exchange markets in pre-crisis period, crisis period and entire period, respectively. In Table 1, we notice that the mean of foreign exchange market returns are positive except Japan, South Africa, Switzerland, Taiwan and U.S. Another noteworthy statistic of the foreign exchange rate returns is a high value of kurtosis. This suggests that, for these markets, big shocks of either sign are more likely to be present and that the foreign exchange return series may not be normally distributed (Chiang et al., 2007). Moreover, findings of Jarque Bera test indicate that foreign exchange market returns do not have normal distribution except Canada. Almost, all of the foreign exchange market returns have serial correlation except Canada, Malaysia and Mexico. Table 2 presents the descriptive statistics during the crisis period. In crisis period, the mean of foreign exchange market returns are positive for 11 countries. In similar with pre-crisis period, foreign exchange rate returns have high value of kurtosis and we reject the null hypothesis of series have normal distribution for all of the countries (Fig. 2). For the most countries, the mean of foreign exchange market returns in the pre-crisis period are greater than those in the crisis-periods. The standard deviation of foreign exchange returns in the pre-crisis period are lower than those in the crisis-period. All the foreign exchange returns are in a leptokurtic distribution which is a common characteristics of financial variables.

We graph computed DCCs in Fig. 3. The break-point dates are represented by vertical lines.

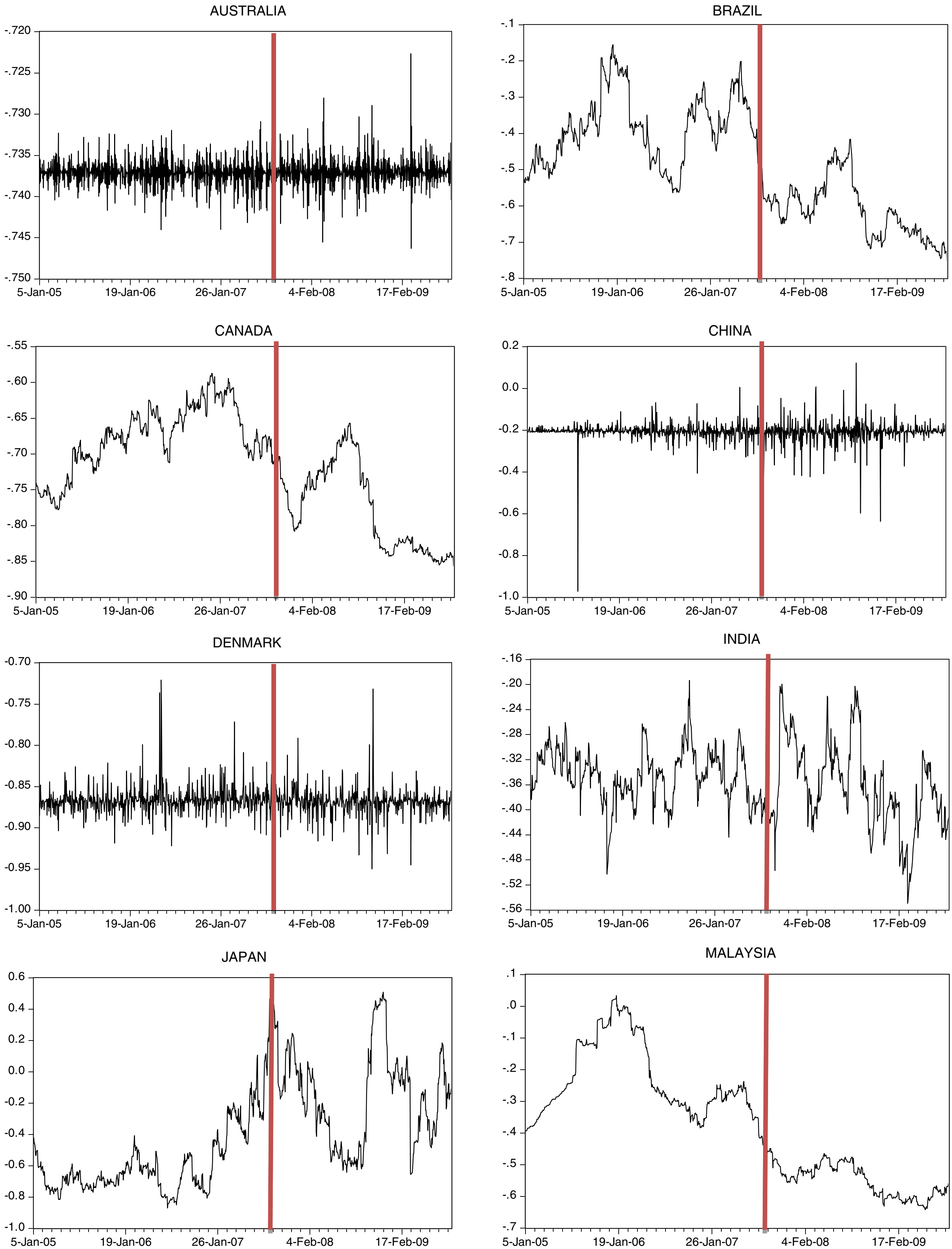


Fig. 3. DCC-GARCH model estimates.

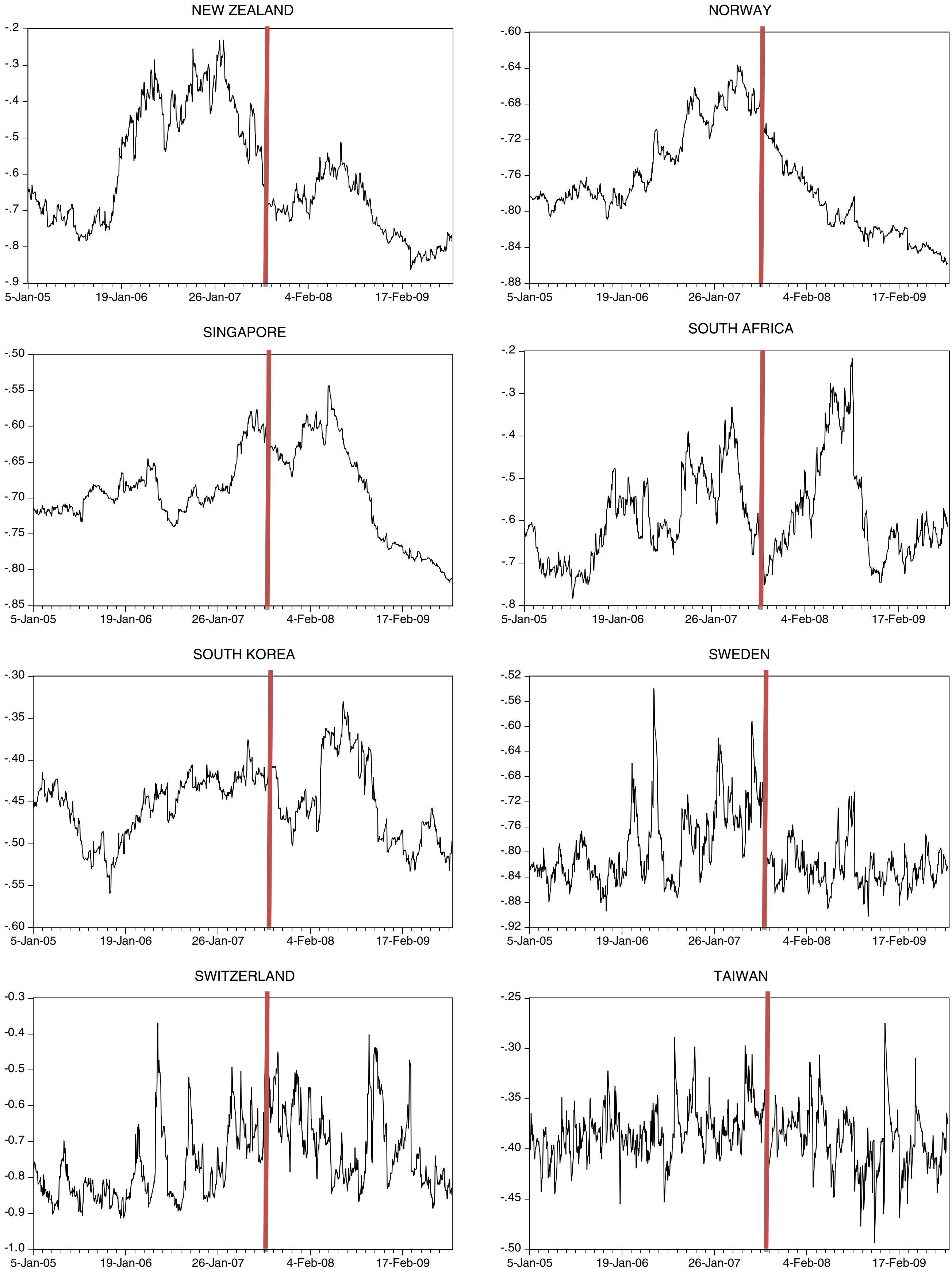


Fig. 3 (*continued*).

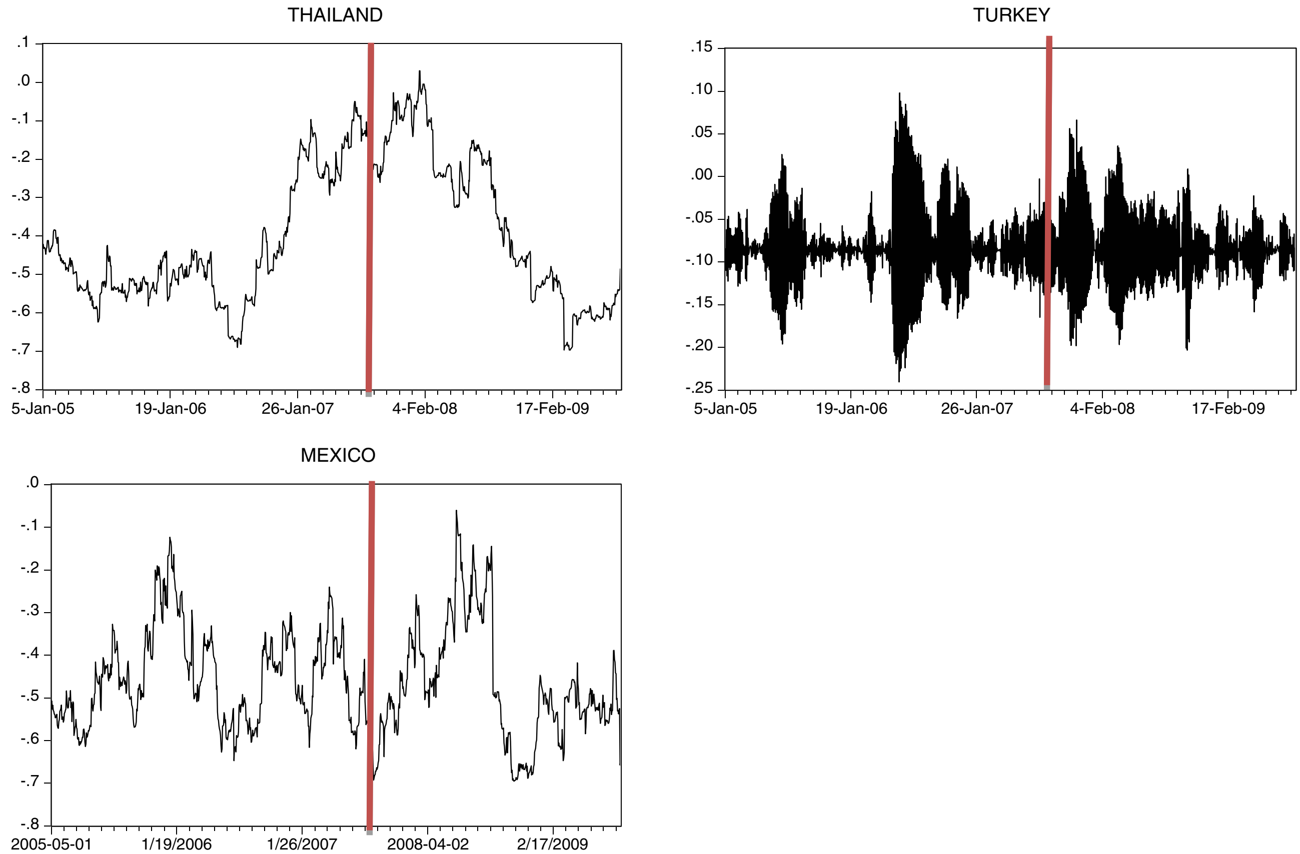


Fig. 3 (*continued*).

Table 4 shows the unconditional correlations and the mean of DCC coefficients in the pre-crisis and crisis periods. When we examine the unconditional correlations, we observe that unconditional correlations increase in crisis periods except Japan, Switzerland, Thailand and Turkey. Similarly, DCC correlations increase in crisis periods except Japan, South Africa, Switzerland and Thailand. Based on the increase in the DCC mean values in percentage term, Malaysia, China and Brazil seem to be the most influenced by the contagion effects from U.S. subprime crisis. This finding is not surprising because all these three markets are emerging markets and due to their unstability, shocks cause to harmful consequences in these markets. To check the existence of contagion, we employ t-tests to test whether DCC correlations coefficients are different in pre-crisis and crisis periods or not. Table 5 shows the findings of t-tests. In Table 5 we can not reject the null hypothesis of the mean of DCC correlations are same in crisis and pre-crisis periods for Japan, South Africa, Switzerland and Thailand. However, we reject the null hypothesis of no contagion for Australia, Brazil, Canada, China, Denmark, India, Malaysia, Mexico, NewZealand,

Table 4
Comparative analysis of unconditional correlation and DCC.

	Unconditional correlation			Dynamic conditonal correlation		
	Pre-crisis	Crisis	% difference	Pre-crisis	Crisis	% difference
Australia	−0.7263	−0.8001	10.1611	−0.7079	−0.7791	10.0579
Brazil	−0.3757	−0.6766	80.0905	−0.3543	−0.6645	87.5529
Canada	−0.6769	−0.8300	22.6178	−0.6608	−0.8056	21.9128
China	−0.1151	−0.2281	98.1755	−0.1316	−0.2766	110.1823
Denmark	−0.8564	−0.8869	3.5614	−0.8448	−0.8913	5.5042
India	−0.2766	−0.4459	61.2075	−0.3224	−0.4017	24.5967
Japan	−0.6831	0.0394	−105.7678	−0.6468	−0.0730	−88.7136
Malaysia	−0.2422	−0.5409	123.3278	−0.2252	−0.5703	153.2415
Mexico	−0.4624	−0.6361	37.5649	−0.4370	−0.5094	16.5675
NewZealand	−0.5352	−0.7827	46.2444	−0.5130	−0.7362	43.5087
Norway	−0.7305	−0.8254	12.9911	−0.7140	−0.8351	16.9607
Singapore	−0.6983	−0.7866	12.6450	−0.6755	−0.7540	11.6210
South Africa	−0.6378	−0.6646	4.2019	−0.6048	−0.5915	−2.1990
South Korea	−0.4604	−0.5484	19.1138	−0.4511	−0.4723	4.6996
Sweden	−0.7871	−0.8349	6.0729	−0.7692	−0.8430	9.5943
Switzerland	−0.8173	−0.6656	−18.5611	−0.7976	−0.6898	−13.5155
Taiwan	−0.3910	−0.3987	1.9693	−0.3469	−0.4384	26.3764
Thailand	−0.2948	0.2984	−201.2212	−0.4128	−0.3882	−5.9593
Turkey	−0.0726	0.0773	−206.4738	−0.0747	−0.0962	28.7817

Note: pre-crisis period is from 03.01.2005 to 16.07.2007. Crisis period is from 17.07.2007 to 31.08.2009. Entire period is from 03.01.2005 to 31.08.2009.

Table 5
Dynamic conditional correlation coefficient and contagion effect test.

	Mean	Variance	t-statistic $H_0 = \mu_\rho^{crisis} = \mu_\rho^{pre-crisis}$
Pre-crisis DCC US_AUSTRALIA	−0.71	0.00	55.89***
Crisis DCC US_AUSTRALIA	−0.78	0.00	
Pre-crisis DCC US_BRAZIL	−0.35	0.04	106.70***
Crisis DCC US_BRAZIL	−0.66	0.00	
Pre-crisis DCC US_CANADA	−0.66	0.00	55.53***
Crisis DCC US_CANADA	−0.80	0.00	
Pre-crisis DCC US_CHINA	−0.13	0.00	53.52***
Crisis DCC US_CHINA	−0.28	0.00	
Pre-crisis DCC US_DENMARK	−0.84	0.00	26.93***
Crisis DCC US_DENMARK	−0.89	0.00	
Pre-crisis DCC US_INDIA	−0.32	0.01	14.41***
Crisis DCC US_INDIA	−0.40	0.01	
Pre-crisis DCC US_JAPAN	−0.65	0.02	−48.57***
Crisis DCC US_JAPAN	−0.09	0.06	
Pre-crisis DCC US_MALAYSIA	−0.22	0.01	76.41***
Crisis DCC US_MALAYSIA	−0.57	0.00	
Pre-crisis DCC US_MEXICO	−0.43	0.02	8.37***
Crisis DCC US_MEXICO	−0.50	0.01	
Pre-crisis DCC US_NEWZEALAND	−0.51	0.02	30.36***
Crisis DCC US_NEWZEALAND	−0.73	0.01	
Pre-crisis DCC US_NORWAY	−0.71	0.00	77.14***
Crisis DCC US_NORWAY	−0.84	0.00	
Pre-crisis DCC US_SINGAPORE	−0.68	0.00	23.57***
Crisis DCC US_SINGAPORE	−0.75	0.01	
Pre-crisis DCC US_SOUTH AFRICA	−0.60	0.01	−3.41***
Crisis DCC US_SOUTH AFRICA	−0.58	0.01	
Pre-crisis DCC US_SOUTH KOREA	−0.45	0.00	6.08***
Crisis DCC US_SOUTH KOREA	−0.47	0.00	
Pre-crisis DCC US_SWEDEN	−0.77	0.00	27.94***
Crisis DCC US_SWEDEN	−0.84	0.00	
Pre-crisis DCC US_SWITZERLAND	−0.80	0.01	−19.06***
Crisis DCC US_SWITZERLAND	−0.69	0.01	
Pre-crisis DCC US_TAIWAN	−0.35	0.00	56.56***
Crisis DCC US_TAIWAN	−0.44	0.00	
Pre-crisis DCC US_THAILAND	−0.44	0.02	−6.58***
Crisis DCC US_THAILAND	−0.37	0.03	
Pre-crisis DCC US_TURKEY	−0.07	0.00	4.06***
Crisis DCC US_TURKEY	−0.09	0.00	

Note: pre-crisis period is from 03.01.2005 to 16.07.2007. Crisis period is from 17.07.2007 to 31.08.2009. Entire period is from 03.01.2005 to 31.08.2009. ***, ** and * indicate the significance level at 1%, 5%, 10% respectively.

Norway, Singapore, South Korea, Sweden, Taiwan and Turkey. Therefore, we find the evidence of contagion effect of U.S. subprime crisis on most of the emerging and developed markets.

5. Summary and conclusion

This paper aims to test the existence of financial contagion between foreign exchange markets during the U.S. subprime crisis by employing DCC-GARCH model which has some advantages over the other methodologies. We examine the contagion effect of U.S. subprime crisis on 10 emerging and 9 developed markets for the period 2005–2009. Main findings of the analyses are as follows: As a result of analysis, we find the evidence of contagion during U.S. subprime crisis for most of the developed and emerging countries. This supports that of Hwang et al. (2010) who find the evidence of financial contagion not only in emerging markets but also in developed markets during the U.S. subprime crisis. In addiditon to this paper, Naoui et al. (2010) find the financial contagion evidence from U.S. market to Brazil, Korea, Malaysia, Mexico, Singapore supporting the findings of this paper. However, they cannot find the financial contagion effect in China and Taiwan different from our results. Our second finding is that the analysis of the pattern of the conditional correlation coefficients provides no evidence in favor of contagion effects in foreign exchange markets of Japan, South Africa, Switzerland and Thailand. This result is not consistent with that of Horta et al. (2008) who find contagion effect in Japan stock markets. The another finding is that emerging markets seem to be the most influenced by the contagion effects from U.S. This result is expected since emerging markets are more unstable than developed countries. Due to this instability, financial contagion can have wide spread harmful consequences in emerging countries. The findings of paper are important for policy makers in emerging markets since the instability through financial contagion influences their development. Therefore, policy makers in emerging countries should seek ways to close the channels of contagion to decrease the instability in emerging countries. The findings of the paper may be of interest to international investors and portfolio manager since the high correlation coefficients during crisis periods imply that the gain from international diversification by holding a portfolio consisting of diverse foreign currencies from these contagion countries decrease.

Testing the presence of financial contagion on other asset markets and using high frequency data will provide broader evidence on financial contagion.

References

Aloui, R., Aissa, M.S.B., Nguyen, D.K., 2011. Global financial crisis, extreme interdependences, and contagion effects: the role of economic structure? Journal of Banking and Finance 35 (1), 130–141.

Bae, K.H., Karolyi, G.A., Stulz, R.M., 2003. A new approach to measuring financial contagion. Review of Financial Studies 16 (3), 717–763.

Bekaert, G., Harvey, C.R., Ng, A., 2005. Market integration and contagion. Journal of Business 78 (1), 39–69.

Bollerslev, T., Engle, R.F., Wooldridge, M., 1992. A capital asset pricing model with time series varying covariance. Journal of Political Economy 96, 116–131.

Bordo, M., Eichengreen, B., 1999. Is our current international environment unusually crisis prone? In: Gruen, D. (Ed.), Capital Flows and the International Financial System. Reserve Bank of Australia, Sydney, pp. 18–74.

Bouaziz, M.C., Selmi, N., Boujelbene, Y., 2012. Contagion effect of the subprime financial crisis: evidence of DCC multivariate GARCH models. European Journal of Economics, Finance and Administrative Sciences (44), 66–76.

Boyer, B., Kumagai, T., Yuan, K., 2006. How do crises spread? Evidence from accessible and inaccessible stock indices. Journal of Finance 61, 957–1003.

Calvo, S., Mendoza, E., 2000. Rational contagion and the globalization of securities markets. Journal of International Economics 51, 79–113.

Chiang, T.C., Jeon, B.N., Li, H., 2007. Dynamic correlation analysis of financial contagion: evidence from Asian markets. Journal of International Money and Finance 1026–1228.

Cho, J.H., Parhizgari, A.M., 2008. East Asian financial contagion under DCC-GARCH. International Journal of Banking and Finance 6 (1).

Corsetti, G., Pericoli, M. and Sbracia, M. (2002), Some contagion, some interdependence': more pitfalls in testing for contagion, Mimeo University of Rome.

Corsetti, G., Pericoli, M., Sbracia, M., 2005. Some contagion, some interdependence: more pitfalls in tests of financial contagion. Journal of International Money and Finance 24, 1177–1199.

Coudert, Virginie, Gex, Mathieu, 2008. Contagion in the credit default swap market: the case of the GM and Ford crisis in 2005. CEPII, Working Paper.

Dungey, M., 2009. The tsunami: measures of contagion in the 2007–08 credit crunch. Cesifo Forum 9 (4), 33–34.

Dungey, M., Fry, R., Martin, V.L., 2004. Currency market contagion in the Asia-Pacific region. Australian Economic Papers 43 (4), 379–395.

Dungey, M., Fry, R.A., González-Hermosillo, B., Martin, V.L., 2006. Contagion in international bond markets during the Russian and LTCM crises. Journal of Financial Stability 2 (1), 1–27.

Eichengreen, B., Rose, A.K., Wyplosz, C., 1995. Exchange market mayhem: the antecedents and aftermath of speculative attacks. Economic Policy 21, 249–312.

Eichengreen, B., Rose, A.K., Wyplosz, C., 1996. Contagious currency crises. NBER Working Paper, 5681.

Engle, R.E., 2002. Dynamic conditional correlation: a simple class of multivariate generalized autoregressive conditional heteroskedasticity models. Journal of Business and Economic Statistics 20, 339–350.

Favero, C.A., Giavazzi, F., 2002. Is the international propagation of financial shocks non-linear? Evidence from the ERM. Journal of International Economics 57 (1), 231–246.

Forbes, K., Rigobon, R., 2002. No contagion, only interdependence: measuring stock market co-movements. Journal of Finance 57 (5), 2223–2261.

Glick, R., Rose, A.K., 1999. Contagion and trade: why are currency crises regional? Journal of International Money and Finance 18 (4), 603–617.

Horen, N.V., Jager, H., Klaassen, F., 2006. Foreign exchange market contagion in the asian crisis: a regression based approach. Review of World Economics 142 (2), 374–401.

Horta, P., Mendes, C., Vieira, I., 2008. Contagion effects of the US subprime crisis on developed countries. CEFAGE-UE Working Paper.

Hwang, I., Haeuck In, F., Kim, T.S., 2010. Contagion effects of the U.S. subprime crisis on international stock markets. Finance and Corporate Governance Conference 2010 Paper.

Ismailescu, Iuliana, Kazemi, Hossein B., 2008. Is there any contagion in emerging debt markets?Available at SSRN http://ssrn.com/abstract=1496365, http://dx.doi.org/10.2139/ssrn.1496365.

Jorion, P., Zhang, G., 2007. Good and bad credit contagion: evidence from credit default swap. Journal of Financial Economics 84 (3), 860–883.
Kaminsky, G.L., Reinhart, C.M., 1999. The twin crises: the causes of banking and balance of payments problems. American Economic Review 89 (3), 473–500.
Kaminsky, G.L., Schmukler, S.L., 1999. What triggers market jitters? A chronicle of the Asian crisis. Journal of International Money and Finance 18, 537–560.
Khan, S., Park, K.W., 2009. Contagion in the stock markets: the Asain financial crisis revisited. Journal of Asian Economics 20, 561–569.
Kodres, L.E., Pritsker, M., 2002. A rational expectations model of financial contagion. Journal of Finance 57 (2), 768–799.
Lhost, J., 2004. The Cause, Effects, and Implications of Financial Contagion, Jonathan Lhost's entry for "The 2004 Moffatt Prize in Economic Writing".
Longstaff, F.A., 2010. The subprime credit crisis and contagion in financial markets. Journal of Financial Economics 97 (3), 436–450.
Naoui, K., Liouane, N., Brahim, S., 2010. A dynamic conditional correlation analysis of financial contagion: the case of the subprime credit crisis. International Journal of Economics and Finance 2 (3), 85–96.
Syllignakis, M.N., Kouretas, G.P., 2011. Dynamic correlation analysis of financial contagion: evidence from the Central and Eastern European markets. International Review of Economics & Finance 20 (4), 717–732.
Tai, C.S., 2003. Looking for contagion in currency futures markets. Journal of Futures Markets 23 (10), 957–988.
Tai, S.C., 2007. Market integration and contagion : evidence from Asian emerging stock and foreign exchange markets. Emerging Markets Review 8 (4), 264–283.
Van Rijckeghem, C.V., Weder, B., 2001. Sources of contagion: is it finance or trade? Journal of International Economics 54, 293–300.