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On the dynamics of volatility transmission: an empirical investigation on G-8 countries

Abstract

This paper investigates the volatility transmission in the financial markets of G-8 countries by using the VAR-EGARCH techniques. From the empirical analyses, it shows that volatility transmissions are present between the G-8 countries during the period from 1995 to 2007. The analyses indicate that the volatilities of some of the G-8 countries are due to the volatility from other markets. Of the countries whose volatilities are significantly affected by the volatility of other markets are: Canada, France, Italy, the UK and the USA. Among these five countries, Canada, the UK and the USA seem to be very highly inter-related. The countries that are very dominant in terms of transmitting volatility are: Russia and the USA. Interestingly, Japanese markets do not seem to have any significant effect on other G-8 markets. However, there have been significant volatility transmissions from the financial markets of Canada, Russia and the UK to the Japan markets. The paper contributes to the literature by studying the volatility transmission among the G-8 countries using the daily stock market data. It shows that the volatility transmission among the developed markets exist and seem to persist over time.

Keywords: volatility, transmission, heteroskedasticiy, spillover, E-GARCH, G-8 countries.
JEL Classification: G10, G14, G15.

Introduction

Globalization and return volatility across the financial markets drew attention to academicians and practitioners since the financial turmoil of the late 80's and early 90's. Researchers are interested in finding out the impact of shocks in return and volatility across different international stock markets and in exploring the direct and indirect impact of squared innovations from other markets on a particular market. Researchers are also interested in exploring whether the shocks have symmetric or asymmetric impact. Recently, researchers start looking closely at the dynamics of correlation in volatility. As a result, a large number of studies have been conducted on volatility spillover during the last two decades. Of those, some notable studies are Karolyi (1995), Koutmos and Booth (1995), Karolyi and Stulz (1996), Booth, Rouge and Koutmos (1998), Kansas (1998), Ng (2000), Engle (2002), Worthington and Higgs (2004), and Francis and Leachman (1996).

The purpose of this paper is to provide further evidences on the return and volatility spillovers in the financial markets among the developed countries. Previous studies by Koutmos (1997) and Francis and Leachman (1996) have collectively reported substantial asymmetry in the first and second moments of return series across the G-7 countries. To account for such an asymmetry, we employ multivariate VAR-EGARH (Vector Autoregressive – Exponential Generalized Autoregressive Conditionally Heteroscedasticity) model to study the behavior of daily closing stock returns of G-8 countries from 1995 to 2007. An EGARCH model makes it possible to investigate the asymmetric impact of good news and bad news on the volatility transmission across these markets. This paper extends Francis and Leachman's (1996) study that used monthly data from April 1973 to July 1990 to model the volatility spillover across stock returns in G-7 countries. In this study, we have used the relatively most recent sample period and most of the developed markets (G-8) that will allow us to incorporate the most recent information to model the transmission in return volatility. Like most of the previous studies, we use impulse response functions to study the nature of persistence of shock in return series. In addition, we use the Granger causality test to explore the direction of price movements. Finally, we also examine the persistence of shock in volatility transmission.

Our paper contributes to the literature in several ways. First, it uses the relatively recent daily stock returns from eight developed markets to study the volatility transmission. Second, our study investigates the causality of the volatility transmission and directional movement of shocks from one market to another market within our sample.

1. Background and significance

The nature of the international transmission of stock return and volatility has been the focus of several studies. Among those, the most notable studies are: Bennett and Kelleher (1988), von Furstenberg and Jeon (1989), Hamao, Masulis and Ng (1990), King and Wadhwani (1990), Neumark, Tinsley and Tosini (1991), Hamao, Masulis and Ng (1990), Ng, Chang and Chou (1991), and Theodossiou and Lee (1993).

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These studies report several empirical regularities: (1) the volatility of stock returns is time-varying; (2) when volatility is high, the price changes in major markets tend to become highly correlated; (3) correlations in volatility and prices appear to be causal from the United States to other countries; (4) lagged spillovers of price changes and price volatility are found between major markets; (5) markets have become reasonably integrated over the flexible exchange rate period; and (6) the interdependence has increased after the stock market crash in 1987.

In recent years several important findings have enriched the literature. Among them the most important study regarding the G-7 stock markets was conducted by Francis and Leachman (1996). They report a significant asymmetry in the volatility of returns across the markets. In fact, results indicate that the volatility of equity markets in the UK, Germany and the US are the most interlinked. Japan, on the other hand, displayed the most internal isolation in conjunction with significant external impacts. Volatilities in the equity markets of Italy and France were relatively isolated while Canadian volatility was more interactive, particularly with the US. Koutmos (1997) using G-7 countries data shows that forecasts of the conditional first and second moments can be improved by taking into account both the size and sign of past innovations. Tay and Zhu (2000) find a contemporaneous correlation in return and volatility with lag across the Pacific-Rim Stock markets. They conclude that the idiosyncratic factors play a vital role in the return behavior of national stock markets. On the other hand, Ng (2000) develops a model that allows the unexpected return of any particular Pacific Basin market be driven by a local idiosyncratic shock and a global shock and finds evidence of volatility-spillovers across various Pacific Basin stock markets from Japan (regional effects) and the US (global effects).

In a more recent study, Miyakoshi (2003) studies the influence of regional (Japan) and global shocks (US) in the Asian market. Unlike Ng (2000), the paper suggests that it is the global factor, not the regional factor, that influences the Asian market return while the volatility process is more influenced by regional shocks than global shocks. Scheicher (2001) studies the regional and global integration of stock market using data from the three major Eastern European Markets (Hungary, Poland and Czech Republic). The paper concludes that the returns of these markets are influenced by both regional and global shocks but the volatility of these markets is mainly influenced by the regional shocks. Worthington and Higgs (2004) examine the return and volatility transmission among three developed markets and six emerging markets using the Multivariate GARCH model and report that there exists a large and predominantly positive mean and volatility spillover.

Beale (2004) investigates the degree of market interdependence across thirteen European markets using the Regime Switching Models. The results show that regime switches in volatility intensities is both statistically and economically significant. In the context of volatility spillover early works by Koutmos and Booth (1995), Francis and Leachman (1996), Koutmos (1997) and Kansas (1998) show evidence of asymmetry in volatility transmission between major developed stock markets.

Few studies investigate the volatility transmission among the Asian countries during the Asian crisis that took place in the later part of 1990's. By using the VAR-EGARCH model, Francis, Kim, Yoon and Viney (2001) showed that reciprocal volatility transmission existed between Hong Kong and Korea and unidirectional volatility transmission existed between Korea and Thailand. A similar study by Fernandez-Izquierdo and Lafuente (2004) supports the contagion effect between some of the Asian markets and developed markets during the Asian crisis. By using the bi-variate GARCH model they identify the nature of cross-leverage effects for each pair of factors out of three latent factors.

Several other studies investigate the return and volatility linkages in different regions. For example, Singh, Kumar and Pandey (2010) study the price and volatility spillovers across North American, European and Asian stock markets by utilizing the VAR (15) and AR-GARCH models. By studying the stock markets of fifteen countries in these regions, they find that both return and volatility of one market is affected by the performance of those indices that either open or close before that respective index. Another paper by Korkmaz, Cevik and Atukeren (2012) study the return and volatility spillovers among CIVETS countries (Colombia, Indonesia, Vietnam, Egypt, Turkey and South Africa). In this paper, by applying the causality-in-mean and causality-in-variance tests, the authors find that the contemporaneous spillover effect among these countries are generally low. However, the structure of the causal relationship suggests that there are some intra-regional and inter-regional interdependence in return and volatility. Another paper by Poshakwale and Aquino (2008) studies the issue of volatility transmission between ADRs and their underlying stocks. By using the GARCH model, they investigate how changes in the volatility of ADR markets affect the volatility in the markets of the underlying stocks and vice-versa. They find that there is a bi-directional volatility transmission between the ADR markets and the underlying stock markets.

The existence of these studies and results from these studies reinforce our hypothesis that volatility of the G-8 stock markets are affected by the volatility of other G-8 stock markets.

2. Design and methods used

Since the paper by Bollerslev (1986), there has been extensive research on ARCH/GARCH type models. Several modifications have been proposed by the researchers to account for different features. Researchers then began to apply these models in many different areas. One such area is transmission of volatility across the international markets. To facilitate these studies, researches proposed an extension of the basic univariate ARCH and GARCH models to a multivariate framework. Multivariate VAR-EGARCH model has often been used in studying the volatility transmission across markets. This model is relatively easy to estimate compared to any other multivariate GARCH models which are computationally taxing and also has elaborate limitations. The multivariate VAR-EGARCH model can be used to capture the asymmetry in volatility generated by the innovations within and across markets. Apart from these, the most important technical advantage of EGARCH specification is that it does not require the non-negativity constraints on the values of GARCH parameters. Having described the use of multivariate VAR-EGARCH model, the following set of equations explains the model in details:

$$r_{i,t} = \beta_{i,0} + \sum_{j=1}^{N} \beta_{i,j} r_{j,t-1} + \varepsilon_{i,t} \quad for\, i = 1,2,3,\ldots N \tag{1}$$

$$\varepsilon_{i,t} \,|\, \Omega_{t-1} \quad \text{follows } Student\ t\,(O, H_t, \upsilon); \tag{2}$$

$$\sigma^2_{i,t} = \exp\left\{ \alpha_{i,0} + \sum_{j=1}^{N} \alpha_{i,j} f_j(Z_{j,t-1}) + \gamma_i \ln(\sigma^2_{i,t-1}) \right\}, \quad \text{for } \ i = 1,2,\ldots\ldots N \tag{3}$$

$$f_j(Z_{j,t-1}) = |Z_{j,t-1}| - E\left(|Z_{j,t-1}|\right) + \delta_j Z_{j,t-1}, \ \text{for } \ j = 1,2,\ldots. N \tag{4}$$

$$E\left(|Z_{j,t-1}|\right) = (2/\pi)^{1/2} (\Gamma(\nu - 1)/2)\Gamma(\nu/2). \tag{5}$$

Here, $r_{i,t}$ ($r_{i,t} = \ln P_{i,t} - \ln P_{i,t-1}$) is return for market i. The information set Ω_{t-1} contains all the information up to t-1. In addition, $\mu_{i,t}$, $\sigma^2_{i,t}$ and $\sigma_{i,j,t}$ are conditional mean, conditional variance and conditional covariance between market j and i, respectively. Finally, $\varepsilon_{i,t}$ is the innovation ($\varepsilon_{i,t} = r_{i,t} - \mu_{i,t}$) at time t and $z_{j,t}$ is the standardized innovation ($z_{j,t} = \varepsilon_{j,t} / \sigma_{j,t}$). In addition, the setup has a long-term drift coefficient represented by $\beta_{i,0}$. Thus, to model US returns, equation (1) can be rewritten as:

$$\begin{aligned} r_{sp,t} = {} & \beta_{US,0} + \beta_{i,US} r_{US,t-1} + \beta_{i,CAN} r_{CAN,t-1} + \beta_{i,UK} r_{UK,t-1} + \beta_{i,FRA} r_{FRA,t-1} + \beta_{i,GER} r_{GER,t-1} + \\ & + \beta_{i,JAP} r_{JAP,t-1} + \beta_{i,ITA} r_{ITA,t-1} + \beta_{i,RUS} r_{RUS,t-1} + \varepsilon_{US,t}. \end{aligned} \tag{6}$$

In this case, a VAR (1) model has outperformed the other models. The conditional variance $\sigma^2_{i,t}$ has been expressed by equation (2). Moreover, the persistence of volatility is measured by γ_i which has to be less than unity for the unconditional variance to be finite. If $\gamma_i = 1$, then the unconditional variance does not exist and the conditional variance follows an integrated process of order one. The asymmetry in conditional variance is explained by equation (3). In order to model the conditional variance for US return, equation (3) can be rewritten as:

$$\begin{aligned} \mathrm{Ln}\sigma^2_{US,t} = {} & \alpha_{US,0} + \alpha_{i,US} \left| z_{US,t-1} \right| + \delta_{US} z_{US,t-1} + \gamma_i \ln(\sigma^2_{US,t-1}) + \alpha_{i,CAN} \ln \varepsilon^2_{CAN} + \alpha_{i,US} \ln \varepsilon^2_{UK} + \\ & + \alpha_{i,FRA} \ln \varepsilon^2_{FRA} + \alpha_{i,GER} \ln \varepsilon^2_{GER} + \alpha_{i,JAP} \ln \varepsilon^2_{JAP} + \alpha_{i,ITA} \ln \varepsilon^2_{ITA} + \alpha_{i,RUS} \ln \varepsilon^2_{RUS}. \end{aligned} \tag{7}$$

The above specification indicates EGARCH (1,1) model for the US returns. In similar fashion, the conditional variance for rest of the seven markets can be constructed. It is to be noted here that most recent squared residuals from the conditional mean of the other markets will be introduced as an exogenous variable in the conditional variance equation. In this set up the spillover of volatility can be captured by the coefficients of exogenous variables i.e. squared residuals of remaining seven countries. Under the assumption that $\varepsilon_{i,t}$ follow Student t distribution, the log likelihood function for the multivariate EGARCH model in equation (3) can be expressed as:

$$L(\theta) = \sum_{t=1}^{T} l_t(\theta), \text{ where}$$

$$l_t(\theta) = \frac{\Gamma\left[(\eta+\nu)/2\right]}{\left[\Gamma(\nu/2)\pi(\nu-2)^{\eta/2}\right]\left|H_t\right|^{-1/2}} \times \left[1 + 1/(\nu-2)(\varepsilon_t' H_t^{-1} \varepsilon_t)\right]^{-(\eta+\nu)/2}, \quad (8)$$

where, η is the number of variables (in our case it is number of countries) and θ is the parameter vector to be estimated. H_t is the conditional matrix of error vector ε_t. The log-likelihood function is highly nonlinear in θ and, therefore, numerical maximization techniques are used. In this paper, we use the Berndt et al.'s (1974) algorithm to maximize $L(\theta)$.

3. Data description

We have collected daily stock index values of G-8 countries: Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States for the period from January 17, 1995 through April 16, 2007. From those index values, we compute the daily returns, $r_{it} = \ln(P_{i,t}) - \ln(P_{i,t-1})$, where, $P_{i,t}$ is the value of stock index i at time t. We first present the statistical characteristics of all daily index returns that provide us with some insight about the structures of the data. Table 1 in Appendix presents those results. It is notable that the mean return is very close to zero indicating that the return process for all markets is quite stable around its mean. Of all the countries, Russian markets have the highest returns (0.1%) compared to all other countries. The lowest returns are observed in the Japanese markets (-0.01%). The returns of all other countries are very close to one another. Volatility across the markets is also very close to one another ranging from 1.08% (USA) to 2.73% (Russia). Being a newly transformed market economy, it is generally expected that volatility in Russian market would be higher.

It appears that all return series are non-normal. All countries exhibit a significant negative skewness (except Japan). Worthington and Higgs (2004) also find that the Japanese returns show a positive skewness. Kurtosis in all countries exceeds the cut-off value of 3.0 indicating that the return distributions are leptokurtic. Many previous studies including Bekaert and Harvey (1997) and Worthington and Higgs (2004) show that equity returns generally exhibit a leptokurtic distribution. In our sample returns, all index return series fail to pass the Jarque-Bera normality test with a probability equal to zero. Figure 1 in Appendix shows the distribution of residuals from the VAR estimates for all countries. It is evident from the graph that the residuals are very widely distributed for all counties with the exception of Russian return series.

4. Empirical results and discussions

Table 2 in Appendix shows the estimation of GARCH(1,1) results. Probabilities for almost all the t-values are less than 0.01% indicating that those are highly significant. Under the conditional heteroskedasticity model, we observe the persistence of volatility which is measured by ($\beta_1 + \beta_2$) being close to one for all stock markets. In order to analyze the inter-relationship of stock markets of G-8 countries, we first test the significance of the first and the second moments by using restricted VAR-EGARCH model. The maximum likelihood estimates of the model are presented in Table 3 (see Appendix). The autocorrelation coefficients, β, and $\beta_{i,t-1}$ of all countries except for Japan are significant indicating that there are strong correlations of present returns with the past returns. Also, coefficients $\beta_{i,t-1}$ for all countries except France, the UK and the USA are significant. It indicates that past innovations of its own return affects the current return of a country's stock price.

Table 3 also lists the inter-relationship of each country's return with other countries. Coefficients $\beta_{i1,t-1}$ through $\beta_{i7,t-1}$ represent those relationships. As it can be seen in Table 3, spillovers from the past returns of the United States have a significant effect on the Canadian returns. Similarly, past returns of Russia and the United States significantly affect French returns; past returns of Russia affect Germany, past returns of Japan, Russia and the United States affect Italian returns, past returns of Canada and Russia affects Japanese returns, past returns of Canada, Japan and the United States affect the United Kingdom returns, and past returns of Canada and Russia affect the United States returns. Interestingly, no country's return affects the return of Russia.

It is interesting to observe that there is no spillover effect of past returns of France, Italy and the United Kingdom on any other country's returns. The most dominant countries in return spillovers are Russia, the USA and Canada. Russian returns had significant effects on five countries, such as, France, Germany, Italy, Japan and the USA. This may be due to the fact that during this period of time, Russian financial markets have become a major player in the international financial markets. Russia has opened up its markets to international investments that attracted a large number of foreign investors in both of its financial and capital markets. The US returns have significant effects on four countries, such as, Canada, France, Italy and the UK, whereas Canadian returns affect Japanese, the UK and the US returns. There is only one significant cross spillover among these eight countries, i.e., between the US and Canada. Table 4 summarizes the significant cross spillovers among the G-8 countries.

Table 5 (see Appendix) presents the results of volatility interactions within and among the individual countries. It is interesting to observe that conditional variance of returns of all countries is affected by its own volatility spillovers as measured by $\alpha_{i,0}$ and by the persistence of volatility as measured by γ_i. Both coefficients $\alpha_{i,0}$ and γ_i are significant for all countries. Significant coefficients for volatility spillover, $\alpha_{i,0}$, is the indication that there is a strong presence of ARCH effects in each of the countries' own returns. These coefficients range from -0.2016 for Germany to -0.4102 for Russia. Coefficients for volatility persistence, γ_i, are very close to one for all countries, ranging from 0.9770 for Russia to 0.9886 for Germany. It simply means that volatility from period to period (in this case, from day to day) remains quite stable for all countries. As it has been observed in the VAR residual graph (Figure 1), ARCH effect and the volatility persistence in Russian return are the smallest compared to all other countries. The coefficients $\alpha_{i,t-1}$ and δ_i represent absolute and actual relative past residual conditional on past standard deviation respectively. In other words, these two coefficients indicate how residuals of the return series are affected by past volatility. Both of these coefficients are highly significant at < .01% level for all countries.

The coefficients α_{i1} through α_{i7} represent effect of the past volatility shocks of one country on the future volatility of another country. From Table 5, we observe that future volatility of Canadian returns is affected by the past volatility shocks of Russian and the US returns. Similarly, future volatility of France is affected by the past volatility shocks of Russia, future volatility of the UK is affected by past volatility of Canada and the USA, future volatility of Italy is affected by past volatility of the UK, and future volatility of the USA is affected by past volatility shocks of Canada and Russia. The coefficients for these volatility shocks are significant between .01% to 5% levels. Table 4 summarizes these volatility effects of one country on another.

It is interesting to observe that future volatilities of Germany, Japan and Russia are not significantly influenced by the volatility shocks of any other countries. In addition, Japanese volatility does not have any significant effect on the volatility of any other countries. On the other hand, Russia seems to be the most dominant country in terms of influencing the volatility of other countries. It affects volatility of three countries, namely, Canada, France and the USA. The volatility of US affects only two countries, namely, Canada and the UK, and volatility of Canada affects two countries, such as, the UK and the US. The only significant cross volatility is observed between Canadian and the US returns.

Conclusions

In this paper, we have studied the volatility transmission in the financial markets of G-8 countries by using the VAR-EGARCH techniques. From the above discussions on the empirical results, it is fairly clear that volatility transmissions are present between the G-8 countries during the period of 1995 to 2007. The financial markets around the world have experienced some ups and downs during this time period. Some of those ups and downs were due to the volatility transmissions from one market to another market. Our analyses clearly indicate that the volatilities of some of the G-8 countries are due to the volatility from other markets. Of the countries whose volatilities are significantly affected by the volatility of other markets are: Canada, France, Italy, the UK and the USA. Among these five countries, Canada, the UK and the USA seem to be very highly inter-related. This is also evident from their coefficients of correlations which are: 0.2068 between the UK and the USA, 0.1073 between the USA and Canada, and 0.0944 between the UK and Canada. These are the three highest coefficients of correlations of all G-8 countries.

The countries that are very dominant in terms of transmitting volatility are: Russia and the USA. Due to the world-wide presence of the US investors, it is not surprising that the US financial markets overwhelmingly affect other markets throughout the world. In recent years, Russian financial markets have also started playing important role in the global financial transactions due to its shift toward a market economy. Interestingly, Japanese markets do not seem to have any significant effect on other G-8 markets. However, there have been significant volatility transmissions from the financial markets of Canada, Russia and the UK to the Japanese markets. The study contributes to the literature by presenting and documenting that the volatility transmission among these developed countries exists and seems to persist over time. This information is especially useful for international investors in their portfolio decisions.

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Appendix

Table 1. Descriptive statistics for the stock index return from January 17, 1995 through April 16, 2007

	CAN	FRA	GER	ITA	JAP	RUS	UK	USA
Mean	0.0004	0.0004	0.0003	0.0004	-0.0001	0.0010	0.0003	0.0004
Median	0.0011	0.0006	0.0008	0.0008	-0.0001	0.0016	0.0007	0.0006

Table 1 (cont.). Descriptive statistics for the stock index return from January 17, 1995 through April 16, 2007

	CAN	FRA	GER	ITA	JAP	RUS	UK	USA
Maximum	0.0492	0.0645	0.0860	0.0685	0.1294	0.3163	0.0563	0.0557
Minimum	-0.0854	-0.0566	-0.1050	-0.0828	-0.0713	-0.4480	-0.0503	-0.0711
Std. dev.	0.0110	0.0125	0.0156	0.0128	0.0162	0.0273	0.0110	0.0108
Skewness	-0.6798	-0.1234	-0.2439	-0.3544	0.1481	-1.4497	-0.1154	-0.1104
Kurtosis	8.0205	5.2483	6.6516	5.8518	5.5942	44.2601	5.0722	6.5436
Jarque-Bera	3395.313	642.0544	1703.332	1083.695	855.5806	214705.9	545.5686	1582.032

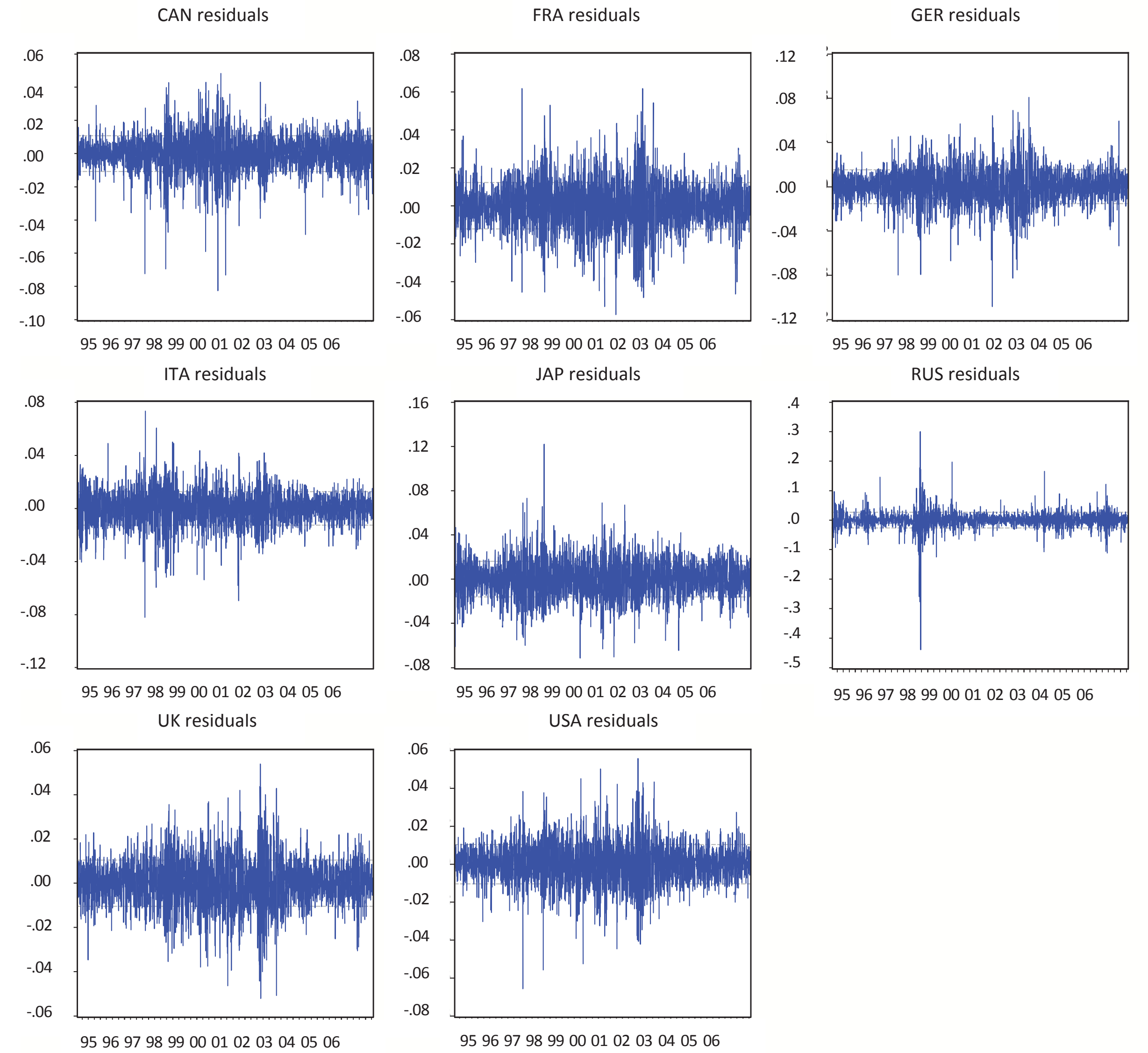

Fig. 1. Estimation of residuals from VAR estimates

Table 2. Parameter estimates for GARCH(1,1) model

Parameters	CAN	FRA	GER	ITA	JAP	RUS	UK	USA
α_0	0.0905 (<.001)	0.0693 (<.001)	0.0007 (0.002)	0.0546 (.004)	0.0214 (.40)	0.1724 (<.001)	0.0582 (<.001)	0.0653 (<.001)
β_0	0.0189 (<.001)	0.0137 (<.001)	0.0001 (<.001)	0.0229 (<.001)	0.0360 (<.001)	0.3158 (<.001)	0.0126 (<.001)	0.0065 (<.001)
β_1	0.1013 (<.001)	0.0695 (<.001)	0.0079 (<.001)	0.0883 (<.001)	0.0701 (<.001)	0.1505 (<.001)	0.0698 (<.001)	0.0677 (<.001)
β_2	0.8885 (<.001)	0.9223 (<.001)	0.0084 (.001)	0.8991 (<.001)	0.9173 (<.001)	0.7962 ((<.001)	0.9195 (<.001)	0.9287 (<.001)
Log-likelihood	-4227.73	-4588.60	8689.58	-4703.68	-5540.08	-6474.23	-4220.21	-4095.67

Note: Values in the parenthesis represent the probabilities of the parameters.

Table 3. Coefficient estimates of conditional mean equations

Coefficients $\beta_{i1,t\text{-}1}$ through $\beta_{i7,t\text{-}1}$ are used to designate the exogenous countries alphabetically after taking out the dependent variable from the list of countries. For example, when Canada is the dependent variable, $\beta_{i1,t\text{-}1}$ represents France and $\beta_{i7,t\text{-}1}$ represents the USA; when Russia is the dependent variable, $\beta_{i5,t\text{-}1}$ represents Japan and $\beta_{i6,t\text{-}1}$ represents the UK; and so on.

Parameters	CAN	FRA	GER	ITA	JAP	RUS	UK	USA
$\beta_{i,0}$	0.0006*	0.0004*	0.0007*	0.0005*	-0.0001	0.0010*	0.0004*	0.0004*
$\beta_{ii,t\text{-}1}$	0.0754*	-0.0029	-0.1178*	0.0559*	-0.0496*	0.2575*	-0.0520	-0.0229
$\beta_{i1,t\text{-}1}$	-0.0006	0.02062	0.0186	0.0016	0.0529*	-0.0035	0.1631*	0.1307*
$\beta_{i2,t\text{-}1}$	0.0013	0.0069	0.0021	0.0308	0.0152	-0.0241	-0.0106	-0.0072
$\beta_{i3,t\text{-}1}$	0.0156	0.0082	0.0157	0.0264*	0.0217	-0.0032	0.0017	0.0024
$\beta_{i4,t\text{-}1}$	-0.0064	-0.0238	0.0022	-0.0135	0.0071	0.0150	-0.0172	0.0155
$\beta_{i5,t\text{-}1}$	0.0129	0.0181*	-0.0239*	0.0171*	0.0191*	0.0055	-0.0257*	-0.0009
$\beta_{i6,t\text{-}1}$	0.0043	0.0227	-0.0047	0.0044	0.0009	0.0029	0.0075	0.0116*
$\beta_{i7,t\text{-}1}$	0.1561*	0.0494*	0.0177	0.0443*	-0.0454	-0.0156	0.1448*	0.0171

Table 4. Cross spillovers of returns from one country to another country

The unidirectional spillovers follow from countries in the columns to the countries in the rows. For example, spillovers from the United States returns affect Canadian returns.

	CAN	FRA	GER	ITA	JAP	RUS	UK	USA
CAN					X		X	X
FRA								
GER				X				
ITA								
JAP							X	
RUS		X	X	X	X			X
UK					X			
USA	X	X		X			X	

Table 5. Coefficient estimates of conditional variance equations

Coefficients α_{i1} through α_{i7} are used to designate the exogenous countries alphabetically after taking out the dependent variable from the list of the G-8 countries. For example, when Canada is the dependent variable, α_{i1} represents France and α_{i7} represents the United States; when Russia is the dependent variable, α_{i5} represents Japan and α_{i6} represents UK; and so on.

Parameters	CAN	FRA	GER	ITA	JAP	RUS	UK	USA
$\alpha_{i,0}$	-0.274*	-0.237*	-0.202*	-0.269*	-0.287*	-0.410*	-0.222*	-0.227*
$\alpha_{i,t\text{-}1}$	0.1378*	0.1294*	0.1312*	0.1580*	0.1234*	0.2597*	0.1117*	0.1042*
δ_i	-0.0277	-0.067*	-0.058*	-0.029*	-0.049*	-0.038*	-0.029*	-0.087*
γ_i	0.9818*	0.9848*	0.9886*	0.9838*	0.9770*	0.9711*	0.9854*	0.9843*
α_{i1}	1.0031	-0.7631	0.6117	-1.7122	-2.0233	0.0528	-2.276*	-2.316*
α_{i2}	0.4632	0.1941	1.6602	-1.5466	-0.0002	-0.1210	-1.2588	0.6273
α_{i3}	-1.6848	-0.0818	0.4049	-0.4411	-1.6452	1.3292	-0.063	1.3535
α_{i4}	0.5796	0.3052	-0.9482	-0.7404	-0.1802	-0.1613	1.3609	-0.5835
α_{i5}	-0.715*	-0.640*	-0.0613	-0.2673	-0.1317	-2.0950	-0.3528	-0.6057
α_{i6}	-0.6698	2.7961	-1.7602	5.1385*	-0.4475	-0.3958	-0.4144	-0.627*
α_{i7}	-4.973*	-1.6004	1.4776	-0.1183	0.2552	2.0214	-2.983*	-1.6709
Adj. R^2	0.0271	0.0090	0.0111	0.01283	0.0046	0.0513	0.0581	0.0201
F-statistic	4.1758*	1.3532	1.6777*	1.9434*	0.6990	8.0874*	9.2218*	3.0794*
Log-likelihood	9811.97	9324.85	8764.32	9213.50	8377.87	7770.47	9762.15	9898.06
Akaike criterion	-6.5035	-6.1799	-5.8076	-6.1059	-5.5509	-5.1474	-6.4704	-6.5606
Schwarz criterion	-6.4616	-6.1380	-5.7657	-6.0640	-5.5090	-5.1055	-6.4285	-6.5187

Note: *Significant at 5% or lower.