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RESEARCH ARTICLE

Asymmetric Volatility Spillovers between U.S. and TSX Stock Markets

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Abstract

This paper using GJR-, E- and DCC-GARCH bi-variate models, and examines the asymmetric volatility spillovers between U.S. and TSX stocks markets using daily returns of 252 Canadian inter-listed stocks for the period 1975-2005. The paper contributes to existing literature by confirming U.S. to be a major transmitter of volatility. Asymmetric co movement and volatility spillovers have increased since 2000. The findings from different models suggest robust inferences on cross-market volatility dynamics are strongly dependent on using more than one multivariate GARCH model.

Keywords: ***Asymmetric volatility, GARCH model, Stock markets.***

Introduction

Asymmetric volatility is induced by overreaction to negative news [1] when contemporaneous returns and conditional return volatility are negatively correlated [2]. The existence of this relationship across financial markets can lead to volatility spillover. Volatility spillover research focuses on inter-market returns and on inter-market volatility shocks [3, 4]. Since much of the research on inter-market volatility transmission examines the spillover effects among markets with non-synchronous trading hours [5], their results are not robust [6]. Also, the robustness of such tests is enhanced by using a time period that covers several business and market cycles [7].

Thus, the topic of inter-market volatility dynamics needs to be revisited by examining co-movement and volatility spillover for the same group of stocks that trade on two different national markets with synchronous trading hours in order to provide a cleaner test of the nature of information flow between the two financial markets, their level of integration and the nature of their interdependence [8]. Cross-listed Canadian stocks appear to be a good choice for such a study since the number of Canadian stocks cross-listed on the TSX and US markets increased from 133 in 1990 [3] to 252 in 2005. These stocks now account for the single largest share of foreign stocks cross-listed on the US markets.Thus, the main objective of this paper is to examine co-movement, asymmetry and volatility spillovers for the 252 Canadian stocks cross-listed on the TSX and US markets over the 1975-2005 period. To ensure inferential sturdiness, the paper uses three bi-variate versions of the popular GARCH (1,1) model (namely, the GJR-, E-, and DCC-GARCH) to examine asymmetry, comovement and volatility transmission for the equal- and value-weighted daily returns for this sample of cross-listed firms.

Sample and Data

Using the TSX Monthly Review, 252 Canadian firms cross-listed on the TSX and U.S. markets are identified as on December 2005. Using daily returns extracted from the CFMRC and the CRSP historical database, both equal- and value-weighted portfolio returns are computed for these 252 cross-listed Canadian stocks.

The basic statistics for these respective return series confirm the stylized facts reported in the literature. Unit root is rejected for both the equal- and value-weighted portfolios of daily returns based on both the Adjusted Dickey-Fuller and Phillips-Perron tests, as well as co-integration between two inter-listed series. These findings reinforce the subsequent decision to use the simple mean model without ARMA terms in the first moment equations of the two GARCH models.

Variance Asymmetry, Co movement, Spillover and Persistence

Variance asymmetry, spillover and persistence are examined using multivariate GARCH framework, which allows for a conditional or time-varying covariance matrix. Three bi-variate models (the GJR-GARCH, E-GARCH, and DCC-GARCH) are used herein. The GARCH(1,1) specification is retained for all three bi-variate models, since research in finance finds that this model is the most robust and parsimonious [9], avoids over-fitting, and is less likely to violate non-negativity constraints [10]. Furthermore, the GARCH (1,1) is not inferior to other models [11], except when other models include a leverage effect (as is done herein). For consistency, the three models have the same mean equations (first-moment condition) but differ only in their conditional variance expressions (second-moment condition). When univariate models are extended to a multivariate framework, an additional constraint must be imposed to ensure that the likelihood function is defined. This constraint is that the conditional covariance matrix is positive definite. Furthermore, the results based on the monthly return series are not reported in the interests of compactness due to their similarity with the results reported herein for the daily return series.

While the mean equations in GJR-GARCH are modeled by Niarchos et al. [8] with MA(1) terms using their own past residuals as well as those of the other series, our Johansen co integration tests rejected the null hypothesis of co integrating vectors in both daily and monthly equal- and value-weighted return series. Hence, past innovations are not included in our mean equations and the returns are regressed only on a constant (intercept).

The first bivariate model considered herein is the GJR-GARCH [12] which is also called the threshold GARCH or T-GARCH. It is simpler and less sensitive to outliers than other GARCH models [13]. The conditional return variances $\sigma^2_{cd,t} = Var\left(\varepsilon_{cd,t} / \Omega_{t-1}\right)$ and $\sigma^2_{us,t} = Var\left(\varepsilon_{us,t} / \Omega_{t-1}\right)$ for the trades for the same securities in the two markets are expressed as:

$$\sigma^2_{cd,t} = \alpha_{cd,1} + \beta_{cd,1} \cdot \varepsilon^2_{cd,t-1} + \beta_{cd,2} \cdot \sigma^2_{cd,t-1} + \beta_{cd,3} \cdot \varepsilon^2_{us,t-1} + \beta_{cd,4} \cdot I_{cd} \cdot \varepsilon^2_{cd,t-1} + \beta_{cd,5} \cdot I_{us} \cdot \varepsilon^2_{us,t-1} \quad (1)$$

$$\sigma^2_{us,t} = \alpha_{us,1} + \beta_{us,1} \cdot \varepsilon^2_{us,t-1} + \beta_{us,2} \cdot \sigma^2_{us,t-1} + \beta_{us,3} \cdot \varepsilon^2_{cd,t-1} + \beta_{us,4} \cdot I_{us} \cdot \varepsilon^2_{us,t-1} + \beta_{us,5} \cdot I_{cd} \cdot \varepsilon^2_{cd,t-1} \quad (2)$$

Persistence in the conditional volatilities is captured by the coefficients $\left(\beta_{cd,2}, \beta_{us,2}\right)$ for the Canadian and US markets, respectively. Asymmetries in the Canadian (cd) and US (us) markets are captured by the coefficients $\beta_{cd,4}$ and $\beta_{cd,5}$, respectively, where $I_{cd} = 1$ if $\varepsilon_{cd,t-1} < 0$ and $I_{us} = 1$ if $\varepsilon_{us,t-1} < 0$. Volatility spillover from the US market to the Canadian market is captured by the coefficient $\beta_{cd,3}$, and by $\beta_{us,3}$ for spillovers in the reserve direction. These estimates reflect the effect of the two squared cross-innovation terms $\left(\varepsilon^2_{us,t-1}, \varepsilon^2_{cd,t-1}\right)$.

The results for the bivariate GJR-GARCH estimations for the portfolios of daily equal- and value-weighted returns are presented in panels A and B of Table 1. All the estimated coefficients (including pair-wise coefficients) for both the equal- and value-weighted series are very significant. Negative [positive] persistence exists in the TSX [US] trades for the equal-weighted series for all the time periods. In contrast, negative persistence exists in the TSX trades (except during 1990-1999) and in the US trades for the value-weighted series. Volatility spillover from the US to the Canadian market increased during 1975-1999 and turned negative during the most recent 2000-2005 period for both the equal- and value-weighted series. Volatility spillover from the Canadian to the US market increased over time for the equal-weighted series and is only significant for the value-weighted series for the period 1990-1999. Thus, the direction of volatility spillover is mainly from the US to the Canadian market for the value-weighted series. The asymmetric response of TSX trades to negative shocks in the US market (and vice versa) for the equal-weighted series decreased after October 1987 but has subsequently increased during 2000-2005.The second bivariate model considered is the exponential GARCH (E-GARCH), which ensures that the logarithmic conditional variances are always positive [8]. The model is given by:

$$Ln\left(\sigma^2_{cd,t}\right) = \alpha_{cd,1} + \beta_{cd,1} \cdot Ln\left(\sigma^2_{cd,t-1}\right) + \beta_{cd,2} \cdot G_{cd,t-1} + \beta_{cd,3} \cdot G_{us,t-1} \quad (3)$$

$$Ln\left(\sigma^2_{us,t}\right) = \alpha_{us,1} + \beta_{us,1} \cdot Ln\left(\sigma^2_{us,t-1}\right) + \beta_{us,2} \cdot G_{us,t-1} + \beta_{us,3} \cdot G_{cd,t-1} \quad (4)$$

Table 1: Bivariate GJR-GARCH

GJR-GARCH	1975-2005		1975-1979		1980-1989		1990-1999		2000-2005	
Coefficient	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**
Panel A: Equal-weighted										
□□□(MeanEqn)	0.0047^{c,f}	0.0044^{c,f}	0.0046^{c,f}	0.0043^{c,f}	0.0050^{c,f}	0.0045^{c,f}	-0.0029^{c,f}	-0.0025^{c,f}	0.0000^{c,f}	-0.0004^{c,f}
□□□(Var Eqn)	0.0048^{c,f}	0.0043^{c,f}	0.0046^{c,f}	0.0041^{c,f}	0.0046^{c,f}	0.0041^{c,f}	0.0042^{c,f}	0.0038^{c,f}	0.0029^{c,f}	0.0033^{c,f}
□□	0.2134^{c,f}	0.1042^{c,f}	0.1924^{c,f}	0.1028^{c,f}	0.1910^{c,f}	0.1078^{c,f}	0.1417^{c,f}	0.1945^{c,f}	0.1493^{c,f}	0.1239^{c,f}
Persistence	-0.0012^{c,f}	0.0042^{c,f}	-0.0012^{c,f}	0.0041^{c,f}	-0.0014^{c,f}	0.0037^{c,f}	-0.0022^{c,f}	0.0026^{c,f}	-0.0916^{c,f}	0.0178^{c,f}
VolSpillover	0.1177^{c,f}	0.2014^{c,f}	0.1092^{c,f}	0.2520^{c,f}	0.1131^{c,f}	0.2405^{c,f}	0.1809^{c,f}	0.4746^{c,f}	-0.0831^{c,f}	0.3199^{c,f}
Asymmetry	-0.1253^{c,f}	-0.0373^{c,f}	-0.1335^{c,f}	-0.0370^{c,f}	-0.1404^{c,f}	-0.0391^{c,f}	-0.0189^{c,f}	0.0088^{c,f}	-0.1792^{c,f}	0.0556^{c,f}
Panel A: Value-weighted										
□□□(MeanEqn)	0.0000^{c,f}	-0.0001^{c,f}	0.0002^{b,f}	0.0000^{c,f}	-0.0016^{c,f}	-0.0019^{c,f}	-0.0022^{c,f}	-0.0026^{c,f}	0.0000^{c,f}	0.0006^{c,f}
□□□(Var Eqn)	0.0036^{c,f}	0.0050^{c,f}	0.0036^{c,f}	0.0049^{c,f}	0.0035^{c,f}	0.0048^{c,f}	0.0035^{c,f}	0.0046^{c,f}	0.0027^{c,f}	0.0041^{c,f}
□□	-0.0270^{c,f}	-0.0738^{c,f}	0.1998^{c,f}	0.0427^{c,f}	0.2004^{c,f}	0.0330^{c,f}	0.1076^{c,f}	-0.0877^{c,f}	0.3490^{c,f}	-0.0263^{c,f}
Persistence	-0.0003^{c,f}	-0.0098^{c,f}	-0.0149^{c,f}	-0.0468^{c,f}	-0.0134^{c,f}	-0.0454^{c,f}	0.0048^{c,f}	-0.0869^{c,f}	-0.0354^{c,f}	-0.0601^{c,f}
VolSpillover	0.1553^{c,f}	0.2966^{c,f}	0.0553^{c,f}	-0.0334^{b,f}	0.0807^{c,f}	-0.0843^{c,f}	0.1928^{c,f}	0.0833^{c,f}	0.0910^{c,f}	-0.1238^{c,f}
Asymmetry	-0.0258^{c,f}	-0.0021^{a,f}	-0.0320^{c,f}	-0.0215^{c,f}	-0.0091^{c,f}	0.0088^{c,f}	-0.0108^{c,f}	0.0056^{c,f}	-0.1195^{c,f}	0.0070^{c,f}

This table reports the estimates of Persistence, Volatility Spillover and Asymmetric response to negative innovations using a bivariate GJR-GARCH for equal- and value-weighted portfolios of daily TSX and US returns. [a], [b] and [c] indicate significance at the 0.10, 0.05 and 0.01 levels, respectively, for a t-test of the null that the estimated coefficient is not different from zero. [d], [e] and [f] indicate significance at the 0.10, 0.05 and 0.01 levels, respectively, for a t-test of the null that the estimated coefficients for the portfolio pairing is not different for the TSX versus the US trades.

where

$$G_{cd,t-1} = \left(\left| \frac{\varepsilon_{cd,t-1}}{\sigma_{cd,t-1}} \right| - \sqrt{\frac{2}{\pi}} \right) + \theta_{cd} \frac{\varepsilon_{cd,t-1}}{\sigma_{cd,t-1}} \qquad (5)$$

$$G_{us,t-1} = \left(\left| \frac{\varepsilon_{us,t-1}}{\sigma_{us,t-1}} \right| - \sqrt{\frac{2}{\pi}} \right) + \theta_{us} \frac{\varepsilon_{us,t-1}}{\sigma_{us,t-1}} \qquad (6)$$

In this model, the asymmetric response in the two markets is captured by the coefficients $(\theta_{cd}, \theta_{us})$ where $\theta_{cd} = 1$ if $\varepsilon_{cd,t-1} < 0$ and $\theta_{us} = 1$ if $\varepsilon_{us,t-1} < 0$. The coefficients $\beta_{cd,3}$ and $\beta_{us,3}$ capture volatility spillover from the US to the Canadian market and vice versa, respectively after reflecting the effect of the two cross-innovation terms $(G_{cd,t-1}, G_{us,t-1})$. The persistence in the conditional volatilities in the two markets is captured by the coefficients $(\beta_{cd,1}, \beta_{us,1})$ [14]. The terms $(G_{cd,t-1}, G_{us,t-1})$ are an asymmetric function of past standardized innovations, and measure the magnitude and sign effect [15].

The results for the bivariate E-GARCH estimations for the portfolio pairings of daily equal- and value-weighted returns are presented in panels A and B of Table 2. In contrast to the estimates from the GJR-GARCH for both the equal- and value-weighted series, the estimated volatility spillovers from both markets have remained virtually unchanged for all the time periods. The asymmetric responses to negative shocks in both markets for both the equal- and value-weighted series increase for all the time periods, with the exception of the asymmetric response for the US trades to negative shocks from the Canadian market for the equal-weighted series. This response declines during 1990-1999 and then increases during 2000-2005.

Table 2: Bivariate exponential-GARCH

E-GARCH	1975-2005		1975-1979		1980-1989		1990-1999		2000-2005	
Coefficient	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**
Panel A: Equal-weighted										
□□□(MeanEqn)	0.0064^{c,f}	0.0015^{c,f}	-0.0035^{c,f}	0.0018^{c,f}	-0.0005^{c,f}	0.0005^{c,f}	0.0009^{c,f}	0.0004^{c,f}	0.0055^{c,f}	0.0045^{c,f}
□□□(Var Eqn)	0.0049^{c,f}	0.0047^{c,f}	0.0046^{c,f}	0.0047^{c,f}	0.0046^{c,f}	0.0047^{c,f}	0.0046^{c,f}	0.0047^{c,f}	0.0046^{c}	0.0046^{c}
□□	0.0046^{c,f}	0.0044^{c,f}	0.0045^{c,f}	0.0040^{c,f}	0.0045^{c,f}	0.0040^{c,f}	0.0045^{c,f}	0.0040^{c,f}	0.0044^{c,f}	0.0039^{c,f}
Persistence	0.0025	0.0025	0.0016^{c}	0.0016^{c}	0.0003^{c,f}	0.0000^{f}	0.0003^{c,f}	-0.0001^{f}	-0.0010^{c,f}	-0.0011^{c,f}
VolSpillover	0.0048^{c,f}	0.0047^{c,f}	0.0046^{c,f}	0.0044^{c,f}	0.0045^{c,f}	0.0044^{c,f}	0.0045^{c,f}	0.0044^{c,f}	0.0045^{c,f}	0.0041^{c,f}
Asymmetry	0.0963^{c,f}	0.0797^{c,f}	0.1376^{c,f}	0.1427^{c,f}	0.3050^{c,f}	0.3815^{c,f}	0.3167^{c,f}	0.2555^{c,f}	0.9037^{c,f}	1.1326^{c,f}
Panel A: Value-weighted										
□□□(MeanEqn)	-0.0004^{c,f}	-0.0001^{c,f}	0.0034^{c,f}	0.0019^{c,f}	0.0024^{c,f}	0.0032^{c,f}	0.0023^{c,f}	0.0019^{c,f}	-0.0015^{c,f}	-0.0001^{c,f}
□□□(Var Eqn)	0.0048^{c,f}	0.0046^{c,f}	0.0047^{c,f}	0.0045^{c,f}	0.0046^{c,f}	0.0044^{c,f}	0.0045^{c,f}	0.0043^{c,f}	0.0045^{c,f}	0.0042^{c,f}
□□	0.0045^{c,f}	0.0041^{c,f}	0.0044^{c,f}	0.0040^{c,f}	0.0042^{c,f}	0.0038^{c,f}	0.0041^{c,f}	0.0037^{c,f}	0.0040^{c,f}	0.0036^{c,f}
Persistence	0.0045^{c,f}	0.0061^{c,f}	0.0030^{c,f}	0.0051^{c,f}	0.0031^{c,f}	0.0019^{c,f}	0.0029^{c,f}	0.0018^{c,f}	0.0008^{c,f}	0.0000^{f}
VolSpillover	0.0047^{c}	0.0047^{c}	0.0044^{c,f}	0.0045^{c,f}	0.0044^{c,f}	0.0045^{c,f}	0.0045^{c,f}	0.0046^{c,f}	0.0044^{c,f}	0.0046^{c,f}
Asymmetry	0.0755^{c,f}	0.0767^{c,f}	0.1828^{c,f}	0.1802^{c,f}	0.2094^{c,f}	0.3421^{c,f}	0.2337^{c,f}	0.3984^{c,f}	0.8726^{c,f}	1.0363^{c,f}

This table reports the estimates of Persistence, Volatility Spillover and Asymmetric response to negative innovations using a bivariate E-GARCH for equal- and value-weighted portfolios of daily TSX and US returns. [a], [b] and [c] indicate significance at the 0.10, 0.05 and 0.01 levels, respectively, for a t-test of the null that the estimated coefficient is not different from zero. [d], [e] and [f] indicate significance at the 0.10, 0.05 and 0.01 levels, respectively, for a t-test of the null that the estimated coefficients for the portfolio pairing is not different for the TSX versus the US trades.

The final model used herein is the Dynamic Conditional Correlation (DCC-GARCH) model of Engle [16], which estimates the conditional correlation coefficients and the variance-covariance matrix simultaneously. The univariate GARCH parameters are estimated in the first stage and the DCC parameters in the second stage. For the bi-variate case, the conditional variance-covariance matrix (H_t) in the DCC model may be expressed as:

$$H_t = D_t \, R_t \, D_t \quad (7)$$

where $R_t = \{\rho_{ij}\}_t$ is the conditional correlation matrix , and D_t is the diagonal matrix of time-varying standard deviations from univariate GARCH models such that:

$$[H_t]_{i,j} = h_{i,j,t} \qquad [D_t]_{i,j} = \sqrt{h_{ij}} \ \forall \ i = j \ \& \ 0 \ \forall \ i \neq j \quad (8)$$

The elements of D_t follow a univariate GARCH(1,1), and for the bivariate CN-US case can be expressed as:

$$\begin{aligned} h_{cn,t} &= \omega_{cn} + \alpha_{cn,1}\, \varepsilon^2_{cn,t-1} + \beta_{cn,1}\, h_{cn,t-1} \\ h_{us,t} &= \omega_{us} + \alpha_{us,1}\, \varepsilon^2_{us,t-1} + \beta_{us,1}\, h_{us,t-1} \end{aligned} \quad (9)$$

The volatility co-movements and spillovers are incorporated into the conditional variance equations (h_{it}) as in Balasubramanyan [17] as follows:

$$\begin{aligned} h_{cn,t} &= \omega_{cn} + \alpha_{cn}\, \varepsilon^2_{cn,t-1} + \beta_{cn}\, h_{cn,t-1} + \gamma_{cn}\, \varepsilon^2_{us,t} + \theta_{cn}\, \varepsilon^2_{us,t-1} \\ h_{us,t} &= \omega_{us} + \alpha_{us}\, \varepsilon^2_{us,t-1} + \beta_{us}\, h_{us,t-1} + \gamma_{us}\, \varepsilon^2_{cn,t} + \theta_{us}\, \varepsilon^2_{cn,t-1} \end{aligned}$$
(10)

where β_{cn}, β_{us} are coefficients that reflect persistence, γ_{cn}, γ_{us} are coefficients that reflect contemporaneous co-movement, and the coefficients θ_{cn}, θ_{us} reflect volatility spillover (US to the Canadian market and vice versa, respectively).Incorporating asymmetry into the measures of co-movement and spillover in the DCC-GARCH model yields:

$$\begin{aligned} h_{cn,t} &= \omega_{cn} + \alpha_{cn}\varepsilon^2_{cn,t-1} + \beta_{cn}h_{cn,t-1} + \gamma_{cn}\varepsilon^2_{us,t} + \theta_{cn}\varepsilon^2_{us,t-1} + \eta_{cn}\varepsilon^2_{us,t}I_{\varepsilon_{us,t}<0} + \psi_{cn}\varepsilon^2_{us,t-1}I_{\varepsilon_{us,t-1}<0} \\ h_{us,t} &= \omega_{us} + \alpha_{us}\varepsilon^2_{us,t-1} + \beta_{us}h_{us,t-1} + \gamma_{us}\varepsilon^2_{cn,t} + \theta_{us}\varepsilon^2_{cn,t-1} + \eta_{us}\varepsilon^2_{cn,t}I_{\varepsilon_{cn,t}<0} + \psi_{us}\varepsilon^2_{cn,t-1}I_{\varepsilon_{cn,t-1}<0} \end{aligned}$$
(11)

where asymmetric co-movements are reflected in the coefficients η_{cn}, η_{us} such that the indicator dummy variables $I_{\varepsilon_{us,t}<0}, I_{\varepsilon_{cns,t}<0}$ each take the value of 1 whenever $\varepsilon_{us,t} < 0 \ \& \ \varepsilon_{cn,t} < 0$ and zero otherwise. The asymmetric volatility spillovers are reflected in the coefficients ψ_{cn}, ψ_{us} such that the indicator dummy variables $I_{\varepsilon_{us,t-1}<0}, I_{\varepsilon_{cn,t-1}<0}$ each take the value of 1 whenever $\varepsilon_{us,t-1} < 0 \ \& \ \varepsilon_{cn,t-1} < 0$ and zero otherwise.

The results from estimating the asymmetric DCC-GARCH model with co-movement and volatility spillovers for the daily equal- and value-weighted series are reported in panels A and B of Table 3. Compared to the DCC model results discussed above, the effects are split into their (a) symmetric co-movements as well as their (a) symmetric volatility spillovers. Contemporaneous co-movements for equal-weighted TSX trades increase (except immediately after the October 1987 crash), and those for the equal-weighted US trades decline during 2000-2005. While co-movements of value-weighted TSX trades remain fairly stationary over the period, those for US trades only decline during 1990-1999. Asymmetric co-movements due to negative shocks in both markets increase for both the equal- and value-weighted series after the October 1987 crash. The direction of volatility spillover for both the equal- and value-weighted series is from the US into the Canadian market, although it is more moderate during 2000-2005. This is confirmed by the negative coefficient for US trades, which reveals the opposite direction of information flow. The measure of asymmetric volatility spillover reveals that negative shocks in the Canadian market lead to a much higher impact on US trades for the equal- versus value-weighted portfolio during 2000-2005.

Summary and Conclusion

This paper examined the time-series behavior in the contemporaneous comovement and asymmetric volatility transmission between US and Canadian markets that have synchronous trading hours, using daily equal- and value-weighted Canadian stocks that are cross-listed on the TSX and US markets. Both the uni-variate GJR-GARCH and E-GARCH models confirm that TSX trades have higher asymmetry compared to the US trades for both equal- and value-weighted daily returns for the same set of stocks. In contrast, the inferences for volatility transmission depend upon the model and return series studied. Based on the findings from the multivariate

GARCH models, contemporaneous and asymmetric comovements declined during the 1990s but have increased more recently due to the

Table 3: Bivariate DCC-GARCH (Asymmetric) estimates of persistence, symmetric and asymmetric comovement and volatility spillovers

Asymmetric DCC	975-2005		975-1979		980-1989		990-1999		000-2005	
Coefficient	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**	**TSX**	**US**
Panel A: Equal-weighted										
□□□(MeanEqn)	0.0014[c,f]	0.0010[c,f]	0.0017[c,f]	0.0013[c,f]	0.0011[c,f]	0.0006[c,f]	0.0012[c,f]	0.0015[c,f]	0.0009[c]	0.0009[c]
□□□(Var Eqn)	0.0001[c,f]	0.0000[c,f]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]
□□	0.0787[c,f]	0.0757[c,f]	0.0700[b,f]	0.0225[f]	0.0675[c,f]	0.0852[c,f]	0.0910[c,f]	0.1669[c,f]	0.1400[c,f]	0.0841[c,f]
Persistence	0.0684[c,f]	0.7877[c,f]	0.0457[f]	0.8208[c,f]	0.7042[c,f]	0.7128[c,f]	0.7206[c,f]	0.7730[c,f]	0.7279[c,f]	0.5441[c,f]
Comovement	0.1117[c,f]	0.1665[c,f]	0.0416[f]	0.1004[c,f]	0.1613[c,f]	0.1972[c,f]	0.1395[c,f]	0.2050[c,f]	0.1946[c,f]	0.1459[c,f]
Vol Spillover	0.0876[c,f]	-0.1341[c,f]	0.0381[f]	-0.0150[f]	-0.0371[c,f]	-0.1125[c,f]	-0.0106[c,f]	-0.0657[c,f]	0.0396[c,f]	0.0036[f]
AsymmComov	0.0555[c,f]	-0.0015[f]	0.0620[a,f]	0.0223[f]	0.0528[c,f]	-0.0296[c,f]	0.0736[c,f]	0.0105[c,f]	0.1462[c,f]	0.0600[c,f]
Asymm VolSpill	0.0227[c,f]	0.0010[f]	0.0244[f]	-0.0780[c,f]	-0.0566[c,f]	0.0160[c,f]	-0.0044[c,f]	-0.0917[c,f]	0.0601[c,f]	0.3252[c,f]
DCC □	0.0090[c]		0.0208		0.0739[c]		0.2011[c]		-0.0008[c]	
DCC □	-0.0965[c]		-0.7925[c]		0.4658[c]		0.7688[c]		0.4099[c]	
Panel B: Value-weighted										
□□□(MeanEqn)	0.0011[c]	0.0011[c]	0.0011[c,f]	0.0009[c,f]	0.0007[c]	0.0007[c]	0.0010[c]	0.0010[c]	0.0010[c,f]	0.0011[c,f]
□□□(Var Eqn)	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]	0.0000[c]
□□	0.0557[c,f]	0.1108[c,f]	0.0699[c,f]	0.0591[c,f]	0.0386[c,f]	0.0614[c,f]	0.0361[c,f]	0.1087[c,f]	0.0546[c,f]	0.0750[c,f]
Persistence	0.8319[c,f]	0.8449[c,f]	0.8522[c,f]	0.8542[c,f]	0.8280[c,f]	0.8437[c,f]	0.8377[c,f]	0.8644[c,f]	0.7733[c,f]	0.8447[c,f]
Comovement	0.0306[c,f]	0.0759[c,f]	0.0379[c,f]	0.1234[c,f]	0.0727[c,f]	0.1326[c,f]	0.0740[c,f]	0.0866[c,f]	0.0737[c,f]	0.1049[c,f]
Vol Spillover	0.0206[c,f]	-0.0625[c,f]	-0.0309[c,f]	-0.0512[c,f]	-0.0066[b,f]	-0.0495[c,f]	-0.0026[c,f]	-0.0832[c,f]	0.0079[c,f]	-0.0790[c,f]
Asymm Comov	0.0678[c,f]	0.0573[c,f]	0.0226[a,f]	-0.0500[b,f]	0.0076[c,f]	-0.0296[c,f]	0.0231[c,f]	0.0283[c,f]	0.0661[c,f]	0.1065[c,f]
Asymm VolSpill	-0.0276[c,f]	-0.0135[b,f]	-0.0112[f]	0.0058[f]	-0.0200[c,f]	0.0227[c,f]	-0.0263[c,f]	-0.0333[c,f]	0.0195[c,f]	0.0089[b,f]
DCC □	0.0928[c]		0.0786[c]		0.0595[c]		0.1176[c]		0.0516[c]	
DCC □	0.8285[c]		0.8986[c]		0.8138[c]		0.6589[c]		0.9090[c]	

This table reports the estimates of Persistence, Contemporaneous and Asymmetric Comovement and Volatility Spillover using a bivariate asymmetric DCC-GARCH model for equal- and value-weighted portfolios of daily TSX and US returns. [a], [b] and [c] indicate significance at the 0.10, 0.05 and 0.01 levels, respectively, for a t-test of the null that the estimated coefficient is not different from zero. [d], [e] and [f] indicate significance at the 0.10, 0.05 and 0.01 levels, respectively, for a t-test of the null that the estimated coefficients for the portfolio pairing is not different for the TSX versus the US trades.

effect of newer and smaller stocks. The symmetric volatility spillovers in both markets similarly declined after increasing during the 1990s, with the exception of the increase in volatility spillover from the US into the Canadian market, as reflected in the equal-weighted returns based on TSX-trades. The asymmetric volatility spillovers due to negative shocks increased [decreased] in both markets based on the E- and DCC- [GJR-] GARCH results. Based on the DCC model results, the asymmetric volatility spillovers due to negative shocks in the Canadian market lead to a much higher impact on US trades for the equal- versus value-weighted return series during 2000-2005. Thus, drawing robust inferences when examining in the dynamics of cross-market volatility depend on using more than one multivariate GARCH model.

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