International Journal of Business Management and Commerce; Vol. 5 No. 1; April 2020
International Journal of Business Management and Commerce
Published by Center for Contemporary Research

International Volatility Transmission and Stock Market Contagion leading up to the Financial Crisis

Robert Antenucci
Assistant Professor Business Management Technology
Kent State University,
4314 Mahoning Ave. N.W.
Warren, OH 44483, USA

Sean Ratican
Assistant Professor Business Management Technology
Kent State University
4314 Mahoning Ave. N.W.
Warren, OH 44483, USA.

Abstract

Markets worldwide are becoming increasingly integrated, and debate continues over the existence of contagion between domestic and foreign financial markets. This study investigated the contagion affect between the U.S. stock market and the Chinese stock market, utilizing stock returns for the S&P 500 and Hang Seng indexes before the subprime mortgage crisis and subsequent great recession. Utilizing this pre-great recession period adds to the literature on international market contagion. This study lends support to the hypothesis that volatility surprises are transmitted internationally from the United States to China, as proxied by these indexes, and that this market contagion existed prior to the recent great recession. This research could be useful in setting regulatory policy on stock market circuit breakers during periods of extreme volatility.

Keywords: Financial Markets, Contagion, Volatility, Regulatory Policy, International Markets

1. Introduction

Markets worldwide are becoming increasingly integrated as political and geographic barriers continue to tumble. A decade has passed since the most recent Great Recession in the United States. Nearly every sector and industry within the U.S. has recovered to pre-recession standards, with many industries exceeding their early 2000s levels. As the globe begins a new decade, it can be beneficial from an econometrics standpoint to examine the concept of international contagion that the US stock market influenced in the years leading up to the recession.

Levitt (1983) maintained that the corporations needed to function as if the world were “one large market” treating the entire planet as if it were a single marketplace with globalization leading to international market integration. Following this reasoning, Koutmos (1997) ignored geographical and cultural drivers, and examined the autocorrelation of six international market indexes, finding asymmetric responses in four of six markets as feedback trading is more intense during market declines. All of Koutmos’s findings on autocorrelation of international returns are consistent with the U.S. market supporting a greater global interdependence in the financial markets. Bekaert and Urias (1999) examined interdependence between emerging and developed markets and found that most emerging markets had low correlation with both developed markets as well as with other emerging markets.

Engle, Ito and Lin (1990) attack the international contagion question by examining intra-day volatility in foreign exchange markets in their research on exchange rates (“Meteor Showers” or “Heat Waves”). They evaluated these two competing theories by examining international volatility transmission and found empirical evidence of volatility spillovers from Japanese Yen to U.S. dollars. Phylaktis and Ravazzolo (2005) studied long-run and short-run dynamics between stock prices and foreign exchange rates to Pacific Basin countries from 1980-1998 finding stock markets and foreign exchange markets are positively related, and that the U.S. markets are primary in facilitating this relationship. Further, they maintained that stock and foreign exchange market linkages are not impacted by foreign exchange restrictions, and that financial disturbances had temporary effects on long-run co-movement of the markets leading them to conclude that international contagion is short-lived.

Along the same lines, Hamao, Masulis, and Ng (1990) examined the transmission of international volatility. They investigated the contagion effects through volatility spillovers by decomposing the typical close to close returns into close-to-open and open-to-close components. Generalized Auto Regressive Conditional Heteroskedasticity (GARCH) is a statistical tool in time-series analysis compensating for variance errors that are serially autocorrelated. This technique corrects for the autoregressive and moving average nature of the variance term. Hamao et. al. (1990) tested volatility spillovers by using the squared residuals from the domestic (U.S.) market as an explanatory variable in a GARCH model on the Tokyo exchange, and found that significant volatility spillover effects from the U.S. (S&P 500) to the Japanese market (Nikkei 225). However, the spillover effects in the other direction from the other two markets (Japan to London and Japan to U.S.) was much weaker.

Numerous data has been presented to acknowledge the spillover effect the U.S. had on Asian stock markets following 2008 (Wang & Wang, 2010; Zhou et al., 2012; Lee, 2013; and Groby, 2015). However, benchmarking the influence of the U.S. prior to 2008 is vital to understanding the varying degrees of influence. Chuliá, Guillén, and Uribe (2015) measured the spillover from the U.S. to seven of the major stock markets in Latin America. There are range-based global stock market spillover effects radiating from the U.S. that impacts international markets (Lee, 2013). When examining 30 years of data sets, there is evidence that volatility spillovers between the US and its major trading partners (Groby, 2015). However, the data indicates that volatility spill overs are particularly impactful during periods of economic turbulence.

Wang and Wang (2010) examined volatility transmissions from the U.S. to the Greater China markets and found a limited correlation. Zhou et al. (2012) confirmed that the U.S. market behavior resulted in volatile impacts on other international markets during the subprime mortgage crisis that resulted in the 2008 U.S. recession. Although prior to 2005, the Chinese stock market demonstrated limited signs of external influence from western counterparts, the Zhou et al. (2012) study indicated positive correlations between the stock markets of Chinese, Japanese, and Indian markets beginning in 2005. Significant spillover from U.S. stock market events in 2008 were significantly correlated with international markets in terms of volatility (Zhou et al., 2012).

Not all research supports international volatility transmission. Craig, Dravid, and Richardson (1995) argued against international volatility transmission by examining foreign based derivatives. They maintained that domestic information released during regular U.S. trading hours had no marginal explanatory powers for changes in overnight levels of the Nikkei index. Further, they empirically demonstrated the S&P index provided no additional contemporaneous information in overnight Japanese returns, and their findings contradict previous contagion models. Barclay, Litzenberger, and Warner (1990) were also suspicious of international contagion. They examined variance in Japanese returns, decomposing the returns into trading and non-trading periods, and they found extremely low volatility during their decomposed overnight period suggesting little or no contagion effect.

This paper expands the research on international contagion in the financial markets by investigating market responses prior to the U.S. subprime mortgage crisis and great recession. As the globe begins a new decade, it can be beneficial from an econometrics standpoint to examine the concept of international contagion that the U.S. stock market influenced in the years leading up to the recession. This paper hypothesizes that volatility does spillover from the United States stock market (S&P 500) into the Chinese stock market (Hang Seng index) and utilizing this pre-great recession period building on the work of Hamao et al. (1990) on international market contagion. This research could be helpful in setting regulatory policy on stock market circuit breakers during extreme volatility.

2. Sample

Daily opening and closing index price data were obtained for the S&P 500 and the Hang Seng stock indexes from January 1, 2003 through December 31, 2007. Domestic returns were calculated using the same decomposition of close-to-close returns into open-to-close and close-to-open as by Hamao et al. (1990). The S&P 500 index returns were calculated from the natural log of the ratio of the opening price to the closing price for the same day while the Hang Seng index returns were calculated from the closing price to the opening price for the following day (or the following day that the market was open). In the United States, the New York Stock Exchange closes as 4pm EST, while six hours later (one trading day later) the stock market opens in Hong Kong. This study examined the price change from the prior NYSE closing price to the subsequent Hang Seng index opening price. When more than one trading day of data was present before trading occurred on the other exchange, the more recent trading day price movement data were used. For example, S&P 500 stock price data for December 24 and December 26 both preceded stock price data December 27 for the Hang Seng Index. Therefore, the study eliminated December 24 S&P 500 return positing that the volatility news in December 24 would also be contained in December 26. The potentially redundant (stale) data eliminated from the sample for the S&P 500 and for the Hang Seng are listed in Table I.

During the 2004 – 2007 sample period, the S&P500 increased from 1,108.48 to 1,478.49, for an average annual log return of 9.8%, while the Hang Seng index increased from 12,801.48 to 27,370.60 for an average annual log return of 20.7%. Summary statistics for the trimmed four-year sample period ("stale" return data removed) are detailed in Table I. Between 2004 and 2007, the mean daily log return for the S&P 500 index was 0.000238 (median of 0.000698) versus a mean return of 0.000588 (median of 0.000716) for the Hang Seng index. The Hang Seng index was slightly more volatile over the period with a daily standard deviation of 0.007829 compared to the S&P 500 index daily standard deviation of 0.007542. A portion of the sample, from November 5, 2007 through December 31, 2007, is given in Table II. A visual examination of the superimposed returns for the S&P 500 index and the Hang Seng index over the three-year time frame indicates that the S&P 500 appeared to be more volatile in late 2004 early 2005 period while in most of 2006 and 2007, the Hang Seng index displayed higher volatility. Further, the volatility for both indexes appeared to increase toward the end of the sample period in 2007. Next, the research shifts to the modelling of both indexes.

3. Methodology

Before modeling the autoregressive components, stationarity tests were performed on both series of returns utilizing Augmented Dickey-Fuller test statistic, and the results indicated that both series are stationary (eliminating the necessity of differencing, etc.). To determine the moving average component (MA), one should focus on the autocorrelation function, and to determine the autoregressive component (AR) requires examining the partial autocorrelation function as (Tsay, 2005). The Hang Seng Index returns indicate significant autocorrelation and partial autocorrelation at the second, third, and fourth lags as well as the tenth, eleventh, and twelfth lags indicating the potential for both autoregressive and moving average modeling.

The initial modeling began with individual autoregressive, AR, and moving average, MA models, but as anticipated, the explanatory effects of the combined ARMA models were significantly greater. Table III details the ARMA modeling progression along with associated values of model selection criterion. The results of the ARMA (2,2) optimal model is detailed in Table IV and the model is as follows:

$$HS_t = 0.000584 - 0.86816HS_{t-1} - 0.944957HS_{t-2} + \varepsilon_t + 0.863830\varepsilon_{t-1} + 0.888755\varepsilon_{t-2}$$

where HS_t and ε_t represents the auto regressive and moving average components respectively. The correlogram of the residuals and squared residuals were then examined for any indication of conditional heteroskedasticity, an irregular pattern or clustering in the variation of the error terms. The residuals were free of autocorrelations; however, the squared residuals showed significant autocorrelation and partial autocorrelations indicating the need for additional modeling work.

This research corrected for the autocorrelation in the squared residuals by utilizing the Generalized Auto Regressive Conditional Heteroskedasticity modeling technique and the technique developed by Bollerslev (1986) where M represents the moving average component, and S represents the autoregressive component. Table V details the optimal model results for the Hang Seng returns, the ARMA (2,2) with GARCH (1,1) yielding the following results:

$$HS_t = 0.0005354 - 0.219283HS_{t-1} + 0.600995HS_{t-2} + \varepsilon_t + 0.243942\varepsilon_{t-1} - 0.617724\varepsilon_{t-2}$$
$$\sigma^2{}_t = 7.82x10^{-7} + 0.080517\varepsilon^2{}_{t-1} + 0.909031\sigma^2{}_{t-1}$$

The GARCH modelling technique resolved the heteroskedasticity issues, as there were no indications of conditional heteroskedasticity in either the residuals or the squared residuals. The model indicates that the current Hang Seng log return is negatively related to the lagged return and positively related to the two-day lagged return, but the current return is positively related to the prior period error term (surprise term), and negatively related to the second lagged error term. Robustness checks of more parsimonious models, e.g. ARMA (1,1) – GARCH (1,1), support the general conclusion of the ARMA (2,2) with GARCH (1,1) being the optimal model.

The study then proceeded with the ARMA modeling of the S&P 500 index returns. The correlogram of the S&P 500 index returns, indicated autocorrelation and partial autocorrelation at the first and eighth lags. ARMA and GARCH procedures and modeling selection criterion, similar to the work on the Hang Seng index returns, were followed. After examining various AR, MA, and ARMA models, the ARMA (2,1) yielded the best model. The correlogram did not indicate any violation of the constant volatility assumption, but the squared residuals displayed heteroskedasticity, as was the case for the correlogram of the squared residuals from the ARMA (2,2) model of the Hang Seng index returns. Utilizing a GARCH (1,2) model for the S&P 500 index returns variance equation eliminated the heteroskedasticity in both the residuals and the squared residuals. The resulting ARMA (2,1) – GARCH (1,2) model is:

$$SP_t = 0.000307 - 1.219283SP_{t-1} - 0.093049SP_{t-2} + \varepsilon_t + 0.931345\varepsilon_{t-1}$$
$$\sigma^2{}_t = 6.91x10^{-7} + 0.0144147\varepsilon^2{}_{t-1} + 1.793896\sigma^2{}_{t-1} - 0.820981\sigma^2{}_{t-2}$$

and the full model results are detailed in Table VI. As indicated by the regression equation, the current S&P 500 return is negatively related to both the first and second lagged returns, but positively related to the first lagged error term.

Next, the research follows the methodology used by Hamao et al. (1990). To test the hypothesis that market volatility spills over form the domestic stock market to the Chinese international stock market, the squared residuals from the S&P 500 index return ARMA (2,1) – GARCH (1,2) model variance equation were utilized as a volatility surprise in the Hang Seng index return variance equation. These squared residuals are input as an external variance regressor in the Hang Seng ARMA (2,2) – GARCH (1,1) model. The revised Hang Seng GARCH equation is now expressed in the following form:

$$\sigma^2{}_t = \alpha_0 + \alpha_1\varepsilon^2{}_{t-1} + \beta\sigma^2{}_{t-1} + fX_t$$

where X_t is the most recent volatility surprise from the domestic market (the S&P 500 squared residual from the open to close returns). The results, detailed in Table VII, indicate that the squared residuals from S&P regression, $\boldsymbol{\varepsilon^2{}_{SPt-1}}$, are positive and highly significant in the Hang Seng GARCH model (greater than one percent), supporting the hypothesis of volatility transmission from the domestic stock market (S&P 500) to the Chinese stock market (Hang Seng). The analysis also examined whether the first lag of the squared residuals from the S&P 500 GARCH model was a significant variance regressor in the volatility model of the Hang Seng Index. When included, both the squared residual and first lag of the squared residual were positive and significant, indicating that the domestic to foreign volatility surprise impact lasts beyond the current day, and that domestic stock market volatility surprises do permeate the Chinses stock market.

4. Results and Conclusions

With worldwide financial markets becoming increasingly integrated, there is still debate over the potential of volatility contagion between domestic and foreign financial markets. This study adds to the body of work on this phenomenon by investigating the contagion affect between the U.S. stock market and the Chinese stock market prior to the subprime mortgage crisis and great recession. As is standard in this area of research, the study utilizes broad based market indexes, the S&P 500 for the U.S. stock market and the Hang Seng for the Chinese stock market data from 2003 to 2007. The research supports that volatility surprises from the domestic market (S&P 500) permeate the Chinese stock market (Hang Seng index) prior to the great recession. Utilizing this pre-great recession period adds to the literature on international market contagion, supporting earlier work by Hamao et al. (1990) and Phylaktis and Rvazzolo (2005). This research could be helpful in setting regulatory policy on stock market circuit breakers during periods of extreme volatility.

Future work by the authors will include investigations into additional foreign equity markets to further support or refute international volatility transmission. Also, with the increasing size of foreign markets, is volatility transmission now a two-way street, and will it diminish the benefits of global diversification, or does the volatility transmission improve market efficiency and ultimately international asset pricing?

References

Barclay, M. J., Litzenberger, R. H., & Warner, J. B. (1990). Private information, trading volume, and stock-return variances. *Review of Financial Studies, 3,* 233-254.

Bekaert, G., & Urias, M. (1999). Is there a free lunch in emerging market equities? *Journal of Portfolio Management*, *25*(3), 83-95.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics, 31*(3), 307-327.

Chuliá, H., Guillén, M., & Uribe, J. M. (2015). Spillovers from the United States to Latin American and G7 stock markets: A VAR quantile analysis. *Emerging Markets Review, 2*(1-2), 63-66.

Craig, A., Dravid, A., & Richardson, M. (1995). Market efficiency around the clock, some supporting evidence using foreign-based derivatives. *Journal of Financial Economics, 39,* 161-180.

Engle, R., Ito, T., & Lin, W. (1990). Meteor showers or heat waves? Heteroskedastic intra-daily volatility in the foreign exchange market. *Econometrica, 58*, 525-542.

Grobys, K. (2015). Are volatility spillovers between currency and equity market driven by economic states? Evidence from the US economy. *Economics Letters, 127*, 72-75.

Hamao, Y., Masulis, R. W., & Ng, V. (1990). Correlations is price changes and volatility across international stock markets. *The Review of Financial Studies,3*(2), 281-307.

Koutmos, G. (1997). Feedback trading and the autocorrelation pattern of stock returns: Further empirical evidence. *Journal of International Money and Finance, 16*, 625-636.

Lee, Y. (2013). Global and regional range-based volatility spillover effects. *Emerging Markets Review, 14*, 1-10.

LeBaron, B. (1992). Some relations between volatility and serial correlations in stock market returns. *The Journal of Business, 65*, 199-219.

Levitt, T. (1983). The Globalization of Markets. *Harvard Business Review*, 92-102

Phylaktis, K., & Ravazzolo, F. (2005). Stock prices and exchange rate dynamics. *Journal of International Money and Finance, 24,*1031-1053.

Tsay, R. S. (2005). *Analysis of financial time series* (Vol. 543). John Wiley & sons.

Wang, P., & Wang, P. (2010). Price and volatility spillovers between the Greater China Markets and the developed markets of US and Japan. *Global Finance Journal, 21*, 304-317.

Zhou, X., Zhang, W., & Zhang, J. (2012). Volatility spillovers between the Chinese and world equity markets. *Pacific-Basin Finance Journal, 20*(2), 247-270.

Table I

Summary Statistics
S&P 500 and Hang Seng Stock Indexes
January 1, 2003 – December 31, 2007
(Sample trimmed of "stale" returns)

	S&P500	Hang Seng
Mean	0.000238	0.000588
Median	0.000698	0.000716
Maximum	0.028803	0.037319
Minimum	-0.035260	-0.039038
Std. Dev.	0.007542	0.007829
Skewness	-0.301681	-0.241081
Kurtosis	4.732187	7.859830
Jarque-Bera	136.5433	967.9297
Probability	0.000000	0.000000
Sum	0.231532	0.572842
Sum Sq. Dev.	0.055347	0.059635
Observations	974	974

Redundant (stale) data eliminated from the sample for the S&P 500

12/24/07, 04/09/07, 04/05/07, 12/26/06, 5/31/06, 5/5/06, 5/1/06, 4/17/06, 1/31/06, 1/30/06, 12/27/05, 10/11/05, 9/19/05, 7/1/05, 5/16/05, 5/2/05, 4/5/05, 3/28/05, 2/11/05, 2/10/05, 2/09/05, 10/22/04, 10/1/04, 9/28/04, 7/1/04, 6/22/04, 5/26/04, 4/12/04, 4/5/04, 1/23/04, and 1/21/04.

Redundant (stale) data eliminated from the sample for the Hang Seng

11/22-11/23/07, 09/03-09/04/07, 05/28-05/29/07, 1/15-1/16/07, 1/2-1/3/07, 11/23-11/24/06, 9/4-9/5/06, 7/4-7/5/06, 5/29-5/30/06, 2/20-2/21/06, 1/16-1/17/06, 11/24-11/25/05, 9/5-9/6/05, 7/4-7/5/05, 5/30-5/31/05, 3/21-3/22/05, 1/17-1/18/05, 11/25-11/26/04, 9/6-9/7/04, 7/5-7/6/04, 6/11-6/14/04, 5/31-6/1/04, 2/16-2/17/04, and 1/19-1/20/04.

Table II
Hang Seng / S&P 500 Sample (12/31/07 – 11/5/07)

S&P 500				Hang Seng				
Date	Open	Close	Return (open to close)	Date	Close	Date	Open	Return (close to open)
12/28/2007	1,479.83	1,478.49	-0.0906%	12/28/2007	27,370.60	12/31/2007	27,437.94	0.2457%
12/27/2007	1,495.05	1,476.27	-1.2641%	12/27/2007	27,842.93	12/28/2007	27,511.54	-1.1974%
12/26/2007	1,495.12	1,497.66	0.1697%	12/24/2007	28,128.80	12/27/2007	28,337.47	0.7391%
12/21/2007	1,463.19	1,484.46	1.4432%	12/21/2007	27,626.92	12/24/2007	27,965.25	1.2172%
12/20/2007	1,456.42	1,460.12	0.2537%	12/20/2007	27,017.09	12/21/2007	27,192.80	0.6483%
12/19/2007	1,454.70	1,453.00	-0.1169%	12/19/2007	27,029.26	12/20/2007	27,034.60	0.0198%
12/18/2007	1,445.92	1,454.98	0.6246%	12/18/2007	26,732.87	12/19/2007	26,880.09	0.5492%
12/17/2007	1,465.05	1,445.90	-1.3157%	12/17/2007	26,596.58	12/18/2007	26,515.09	-0.3069%
12/14/2007	1,486.19	1,467.95	-1.2349%	12/14/2007	27,563.64	12/17/2007	27,236.45	-1.1941%
12/13/2007	1,483.27	1,488.41	0.3459%	12/13/2007	27,744.45	12/14/2007	27,708.31	-0.1303%
12/12/2007	1,487.58	1,486.59	-0.0666%	12/12/2007	28,521.06	12/13/2007	28,518.78	-0.0080%
12/11/2007	1,516.68	1,477.65	-2.6071%	12/11/2007	29,226.84	12/12/2007	28,611.64	-2.1274%
12/10/2007	1,505.11	1,515.96	0.7183%	12/10/2007	28,501.10	12/11/2007	28,947.70	1.5548%
12/7/2007	1,508.60	1,504.66	-0.2615%	12/7/2007	28,842.47	12/10/2007	29,017.70	0.6057%
12/6/2007	1,484.59	1,507.34	1.5208%	12/6/2007	29,558.92	12/7/2007	29,890.64	1.1160%
12/5/2007	1,465.22	1,485.01	1.3416%	12/5/2007	29,345.45	12/6/2007	29,769.15	1.4335%
12/4/2007	1,471.34	1,462.79	-0.5828%	12/4/2007	28,879.59	12/5/2007	28,942.23	0.2167%
12/3/2007	1,479.63	1,472.42	-0.4885%	12/3/2007	28,658.42	12/4/2007	28,544.18	-0.3994%
11/30/2007	1,471.83	1,481.14	0.6306%	11/30/2007	28,643.61	12/3/2007	28,825.03	0.6314%
11/29/2007	1,467.41	1,469.72	0.1573%	11/29/2007	28,482.54	11/30/2007	28,604.68	0.4279%
11/28/2007	1,432.95	1,469.02	2.4860%	11/28/2007	27,371.24	11/29/2007	28,337.11	3.4679%
11/27/2007	1,409.59	1,428.23	1.3137%	11/27/2007	27,210.21	11/28/2007	27,315.93	0.3878%
11/26/2007	1,440.74	1,407.22	-2.3541%	11/26/2007	27,626.62	11/27/2007	26,704.76	-3.3938%
11/23/2007	1,417.62	1,440.70	1.6150%	11/23/2007	26,541.09	11/26/2007	27,398.53	3.1795%
11/21/2007	1,434.71	1,416.77	-1.2583%	11/21/2007	26,618.19	11/22/2007	26,318.21	-1.1334%
11/20/2007	1,434.51	1,439.70	0.3611%	11/20/2007	27,771.21	11/21/2007	27,277.72	-1.7930%
11/19/2007	1,456.70	1,433.27	-1.6215%	11/19/2007	27,460.17	11/20/2007	26,583.64	-3.2441%
11/16/2007	1,453.09	1,458.74	0.3881%	11/16/2007	27,614.43	11/19/2007	27,628.97	0.0526%
11/15/2007	1,468.04	1,451.15	-1.1572%	11/15/2007	28,751.21	11/16/2007	28,037.18	-2.5148%
11/14/2007	1,483.40	1,470.58	-0.8680%	11/14/2007	29,166.01	11/15/2007	29,078.21	-0.3015%
11/13/2007	1,441.35	1,481.05	2.7171%	11/13/2007	27,803.35	11/14/2007	28,787.40	3.4781%
11/12/2007	1,453.66	1,439.18	-1.0011%	11/12/2007	27,665.73	11/13/2007	27,561.57	-0.3772%
11/9/2007	1,467.59	1,453.70	-0.9510%	11/9/2007	28,783.41	11/12/2007	28,061.45	-2.5402%
11/8/2007	1,475.27	1,474.77	-0.0339%	11/8/2007	28,760.22	11/9/2007	28,510.53	-0.8720%
11/7/2007	1,515.46	1,475.62	-2.6641%	11/7/2007	29,708.93	11/8/2007	28,758.72	-3.2507%

Table III

ARMA Modeling Results of Hang Seng Index

	Schwarz Criterion	**Akaike info Criterion**	**Adjusted R^2**
AR (1)	-6.848069	-6.858101	0.000067
MA (1)	-6.848990	-6.859014	0.000078
ARMA (1,1)	-6.849141	-6.864188	0.008176
ARMA (2,1)	-6.847030	-6.867109	0.013874
ARMA (1,2)	-6.846660	-6.866723	0.012719
ARMA (2,2)	**-6.858666**	**-6.883765**	**0.028153**
ARMA (3,2)	-6.853337	-6.883481	0.029281
ARMA (2,3)	-6.853685	-6.883805	0.029185

AR (1) autoregressive model of order 1, AR (2) autoregressive model of order 2, etc.
MA (1) moving average model of order 1, MA (2) moving average model of order 2, etc.
ARMA (1,1) autoregressive moving average model of order 1 and 1 respectively.

Table IV

Hang Seng Index Return ARMA (2,2) Model

$$HS_t = 0.000584 - 0.86816HS_{t-1} - 0.944957HS_{t-2} + \varepsilon_t + 0.863830\varepsilon_{t-1} + 0.888755\varepsilon_{t-2}$$

Dependent Variable: HS				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000584	0.000242	2.407723	0.0162
AR(1)	-0.868164	0.031311	-27.72673	0.0000
AR(2)	-0.944957	0.031317	-30.17397	0.0000
MA(1)	0.863830	0.043177	20.00684	0.0000
MA(2)	0.888755	0.043358	20.49822	0.0000
R-squared	0.032156	Mean dependent var		0.000581
S.E. of regression	0.007724	S.D. dependent var		0.007835
Sum squared resid	0.057696	Akaike info criterion		-6.883765
Log likelihood	3350.510	Schwarz criterion		-6.858666
Durbin-Watson stat	1.941094	F-statistic		8.032116

HS_t Hang Seng Index at time t; HS_{t-1} Hang Seng Index at time $t-1$ autoregressive component; ε_{t-1} moving average component.

Table V

Hang Seng Index Return ARMA (2,2) – GARCH (1,1) Model

$$HS_t = 0.0005354 - 0.21928HS_{t-1} - 0.60100HS_{t-2} + \varepsilon_t + 0.24394\varepsilon_{t-1} - 0.61772\varepsilon_{t-2}$$
$$\sigma^2{}_t = 7.82x10^{-7} + 0.080517\varepsilon^2{}_{t-1} + 0.909031\sigma^2{}_{t-1}$$

Dependent Variable: HS				
GARCH = C(6) + C(7)*RESID(-1)^2 + C(8)*GARCH(-1)				
	Coefficient	Std. Error	z-Statistic	Prob.
C	0.000535	0.000189	2.826503	0.0047
AR(1)	-0.219283	0.341303	-0.642487	0.5206
AR(2)	0.600995	0.319701	1.879868	0.0601
MA(1)	0.243942	0.343844	0.709454	0.4780
MA(2)	-0.617724	0.328765	-1.878923	0.0603
	Variance Equation			
C	7.82E-07	2.51E-07	3.111856	0.0019
RESID(-1)^2	0.080517	0.015665	5.140000	0.0000
GARCH(-1)	0.909031	0.017191	52.87985	0.0000
R-squared	0.006630	Mean dependent var		0.000581
S.E. of regression	0.007838	S.D. dependent var		0.007835
Sum squared resid	0.059217	Akaike info criterion		-7.189131
Log likelihood	3501.918	Schwarz criterion		-7.148972
Durbin-Watson stat	2.021893	F-statistic		0.919104

HS_t Hang Seng Index at time *t*; HS_{t-1} Hang Seng Index at time *t-1* autoregressive component; ε_{t-1} moving average component; $\sigma^2{}_t$ variance at time *t*; $\sigma^2{}_{t-1}$ variance at time *t-1*

Table VI

S&P 500 ARMA (2,1) GARCH (1,2) Model Results

$$SP_t = 0.000307 - 1.219283SP_{t-1} - 0.093049SP_{t-2} + \varepsilon_t + 0.931345\varepsilon_{t-1}$$
$$\sigma^2{}_t = 6.91x10^{-7} + 0.0144147\varepsilon^2{}_{t-1} + 1.793896\sigma^2{}_{t-1} - 0.820981\sigma^2{}_{t-2}$$

Dependent Variable: SP500				
GARCH = C(5) + C(6)*RESID(-1)^2 + C(7)*GARCH(-1) + C(8)				
*GARCH(-2)				
	Coefficient	Std. Error	z-Statistic	Prob.
C	0.000307	0.000215	1.428980	0.1530
AR(1)	-1.000271	0.062894	-15.90414	0.0000
AR(2)	-0.093049	0.033935	-2.741945	0.0061
MA(1)	0.931345	0.053917	17.27363	0.0000
	Variance Equation			
C	6.91E-07	2.30E-07	3.004936	0.0027
RESID(-1)^2	0.014414	0.004176	3.451544	0.0006
GARCH(-1)	1.793896	0.059619	30.08953	0.0000
GARCH(-2)	-0.820981	0.053393	-15.37622	0.0000
R-squared	0.015356	Mean dependent var		0.000229
S.E. of regression	0.007508	S.D. dependent var		0.007539
Sum squared resid	0.054342	Akaike info criterion		-7.031460
Log likelihood	3425.290	Schwarz criterion		-6.991301
Durbin-Watson stat	2.056174	F-statistic		2.147780

SP_t S&P 500 Index at time *t*; HS_{t-1} S&P 500 Index at time *t-1* autoregressive component; ε_{t-1} moving average component; $\sigma^2{}_t$ variance at time *t*; $\sigma^2{}_{t-1}$ variance at time *t-1*; $\sigma^2{}_{t-2}$ variance at time *t-2*.

Table VII

Squared Residual as Explanatory Variable

$$HS_t = 0.01294 + 0.147601HS_{t-1} + 0.851964HS_{t-2} + \varepsilon_t - 0.124867\varepsilon_{t-1} - 0.867418\varepsilon_{t-2}$$
$$\sigma^2{}_t = 1.49x10^{-5} + 0.077795\varepsilon^2{}_{t-1} - 0.674929\sigma^2{}_{t-1} + 0.674929\varepsilon^2{}_{SPt-1}$$

Dependent Variable: HS				
GARCH = C(6) + C(7)*RESID(-1)^2 + C(8)*GARCH(-1) + C(9) *SPSQRESID				
	Coefficient	Std. Error	z-Statistic	Prob.
C	0.012940	0.131295	0.098557	0.9215
AR(1)	0.147601	0.093040	1.586438	0.1126
AR(2)	0.851964	0.093231	9.138191	0.0000
MA(1)	-0.124867	0.088159	-1.416385	0.1567
MA(2)	-0.867418	0.087463	-9.917539	0.0000
	Variance Equation			
C	1.49E-05	1.13E-06	13.21444	0.0000
RESID(-1)^2	0.077795	0.013220	5.884659	0.0000
GARCH(-1)	-0.080862	0.018110	-4.465028	0.0000
SPSQRESID	0.674929	0.059080	11.42401	0.0000
R-squared	0.006406	Mean dependent var		0.000581
S.E. of regression	0.007843	S.D. dependent var		0.007835
Sum squared resid	0.059231	Akaike info criterion		-7.456737
Log likelihood	3632.974	Schwarz criterion		-7.411558
Durbin-Watson stat	2.019549	F-statistic		0.776136

HS_t Hang Seng Index at time *t*; HS_{t-1} Hang Seng Index at time *t-1* autoregressive component; ε_{t-1} moving average component; $\sigma^2{}_t$ variance at time *t*; $\sigma^2{}_{t-1}$ variance at time *t-1*; $\varepsilon^2{}_{SPt-1}$ (SPSQRESID) most recent volatility surprise from the domestic market (the S&P 500 squared residual from the open to close returns).