The Dynamic Correlations among the G7 and China: Evidence from both Realized and Implied Volatilities

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Preliminary and incomplete

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Abstract:

This paper studies the dynamic correlations among the G7 and China by using EGARCH/DCC models proposed by Engle and Figlewski (2014). We find that the correlations among the G7 can be captured by a general correlation structure and a one-factor model when both realized and implied volatilities are used. However, the common factors in the one-factor model are different when the two different volatilities are considered. Particularly, the U.S. is not the common factor in the two cases. Further, there is no significant correlations between China and the G7 countries by using realized volatilities. Nevertheless, the correlations increase during the 2007-2008 financial crisis. Furthermore, there results are robust to subsample analysis and different measures of realized volatilities.

Keywords: Correlation; G7; China; Implied volatility; Realized volatility

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1.Introduction

Recently, Engle and Figlewski (2014) document a general correlation structure and a one-factor model with the VIX as the common factor among implied volatilities (IV) of twenty-eight large cap stocks by developing EGARCH/DCC models. Their empirical study shows that time-varying correlations driven by shocks are correlated across stocks without a common factor and IV changes are also correlated through exposure to a single market volatility process, i.e. VIX index. They also demonstrate that this result could help us to build up a dynamic hedge for the vega risk with a hedging portfolio of IV exposures. Krause and Lien (2014) extend this model and consider both the market volatility factor and the industry volatility factor in the evolution of individual stock option implied volatility. By doing this, the hedging errors are reduced. On the other hand, the importance of correlation across countries in international portfolio choice is emphasized by Ball and Torous (2000) and Buraschi, Porchia and Trojani (2010). However, the correlations among major international stock markets is not explored and what is the difference between correlations derived by using historical and forward-looking information is not clear, which has important implications for international investors.

In this paper, we try to fill this gap by focusing on the G7 and China and using realized and implied volatilities. Specifically, we employ the EGARCH/DCC models proposed by Engle and Figlewski (2014). Recent data also give us an opportunity to investigate the dynamic feature of correlations before, during and after the 2007-2008 financial crisis. We find that the correlations among the G7 can be captured by a general correlation

structure and a one-factor model when both realized and implied volatilities are used. However, the common factors in the one-factor model are different when the two different volatilities are considered. Surprisingly, the U.S. is not the common factor in the two cases. In addition, there is no significant correlations between China and the G7 countries by using realized volatilities. Nevertheless, the correlations increase during the 2007-2008 financial crisis. Robustness check shows that our conclusions remain when subsample analysis and different measures of realized volatilities are considered. Generally speaking, our results demonstrate that the EGARCH/DCC models are also appropriate to model the dynamics of correlations among international stock markets for both realized and implied volatilities.

The rest of the paper proceeds as follows: Section 2 introduces the model and data. In Section 3 we estimate the model and conduct empirical analysis. Section 4 provides robustness check. Section 5 concludes.

2.Model and Data

2.1 Model

We follow Engel and Figlewski (2014) to model correlations by using the EGARCH/DCC models. The reasons why we choose this model are basically from two aspects. First, previous papers point out that the logarithm difference of the volatility follows a symmetric distribution such as normal distribution or student distribution. Meanwhile, since we want to test whether the daily changes of natural logarithm of volatility of different countries are correlated, we introduce an external regressor into our mean equation. Second, the logarithm difference of the volatility is heteroskedastic and

according to the previous literature, the standard deviation of it follows an EGARCH process.

Under this structure, we hope to find out the daily change of a specific country which is representative and use this country as a common external factor. All the other countries could be represented by this common factor to some extent and has the following mathematical expression:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + m_i \ln(\frac{v_{common\ \ factor,t}}{v_{common\ \ factor,t-1}}) + \sigma_{i,t} z_{i,t}$$
$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|\, z_{i,t-1}\,| - E[|\, z_{i,t-1}\,|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

The first equation is the mean equation describing how the realized volatility changes over time. The second is the volatility equation describing how the volatility of realized volatility changes over time. μ is the mean of the daily change of realized volatility's logarithm excluding the effect of the common factor. m measures the effect of the common factor. ω is the mean of the logarithm of the standard deviation of realized volatility excluding the effects of the auto-correlation and the mean model's latest realized error. β measures the effect of the auto-correlation. Both γ and α measure the effect of the mean model's latest realized error. α measures how the absolute value of the error can change the volatility of the realized volatility and γ measures how the numeric value of the error could affect. For the country which serves as the common factor, it has the following mathematical expression:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + \sigma_{i,t} z_{i,t}$$
$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|\, z_{i,t-1}\,| - E[|\, z_{i,t-1}\,|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

It is a standard EGARCH model and the explanation of the coefficients here are just as same as the explanation we have used in the model with an external regressor.

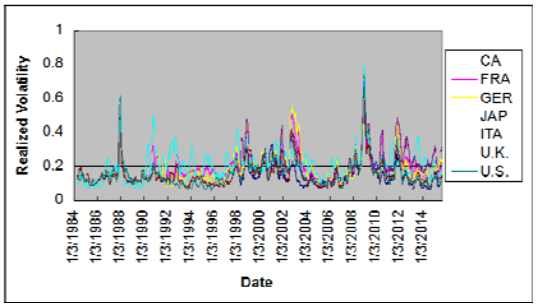
2.2 Data

We collect the historical prices and the implied volatility of seven major indices to study corresponding G7's markets. The seven indices are the followings: S&P/TSX60 index, CAC40 index, DAX index, NIKKEI 225 index, FTSE MIB index, FTSE 100 index and S&P 500 index. All the historical prices are obtained from Yahoo finance except S&P/TSX60 which is downloaded from the TSX website. Then we use these historical prices to calculate the past 60 days, 90 days, 120 days and 180 days realized volatilities. The following graphs and tables display the realized volatility we have calculated:

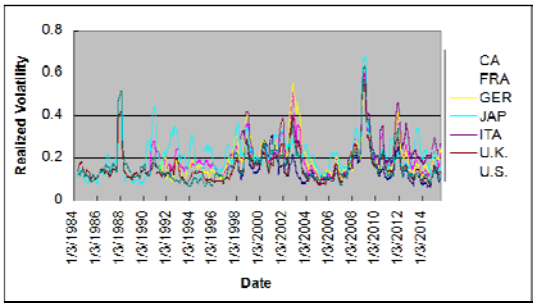
Figure 1. Realized volatility in the whole period

This figure shows realized volatilities of the past 60 days, 90 days, 120 days and 180 days. Panel 1 shows 60 days realized volatility in the whole period. Panel 2 shows 90 days realized volatility in the whole period. Panel 3 shows 120 days realized volatility in the whole period and Panel 4 shows 180 days realized volatility in the whole period.

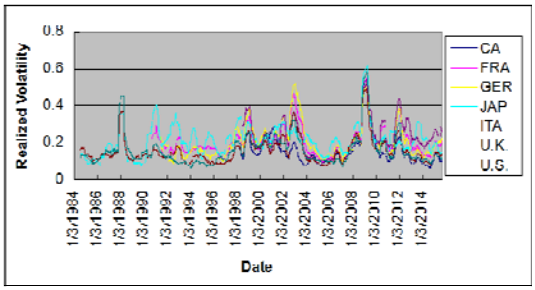
Panel 1: 60 Days



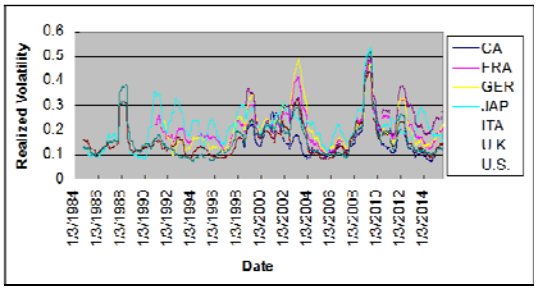
Panel 2: 90 Days



Panel 3: 120 Days



Panel 4: 180 Days



We collect the historical prices of Shanghai Stock Index (SSI) to study the Chinese market. The data are also downloaded from yahoo finance. The time range of the data is from 12/19/1990 to 09/02/2015. As usual, we calculate the 60 days, 90 days, 120 days and 180 days realized volatility of SSI and report them in the following chart:

Figure 2. Realized volatility of China

This figure shows the realized volatility of SSI of 60 days, 90 days, 120 days and 180 days.

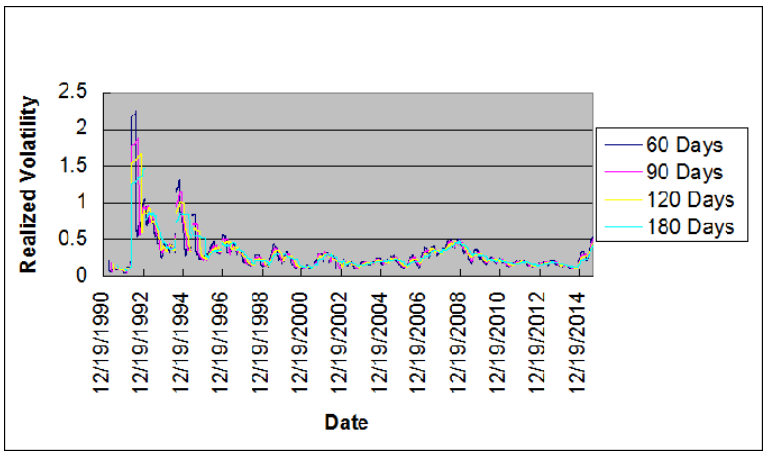


Table 1. Basic statistics of realized volatility of G7 and China in the whole period

This table shows the basic statistics of realized volatility of G7 and SSI for the past 60 days, 90 days, 120 days and 180 days.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.	CHN
60 Days	Mean	0.158	0.205	0.205	0.211	0.225	0.155	0.158	0.306004
	Standard Deviation	0.087	0.087	0.097	0.093	0.104	0.076	0.088	0.265922
	Minimum	0.06	0.086	0.082	0.066	0.069	0.067	0.058	0.044786
	Maximum	0.687	0.7	0.656	0.789	0.668	0.641	0.74	2.254217
	Number of Points	4525	6396	6204	7734	4426	8182	7918	6262
90 Days	Mean	0.159	0.207	0.207	0.213	0.227	0.157	0.16	0.313142
	Standard Deviation	0.084	0.083	0.093	0.087	0.099	0.072	0.085	0.258738
	Minimum	0.063	0.092	0.085	0.076	0.074	0.074	0.063	0.054951
	Maximum	0.602	0.596	0.56	0.681	0.568	0.546	0.637	1.890276
	Number of Points	4495	6366	6174	7704	4396	8152	7888	6232
120 Days	Mean	0.16	0.208	0.208	0.215	0.228	0.158	0.161	0.318809
	Standard Deviation	0.082	0.079	0.09	0.083	0.095	0.07	0.082	0.252988
	Minimum	0.064	0.097	0.085	0.079	0.077	0.076	0.066	0.075837
	Maximum	0.547	0.55	0.529	0.617	0.541	0.494	0.586	1.669056
	Number of Points	4465	6336	6144	7674	4366	8122	7858	6202
180 Days	Mean	0.163	0.21	0.21	0.218	0.23	0.16	0.163	0.327133
	Standard Deviation	0.079	0.075	0.085	0.076	0.09	0.066	0.079	0.244597
	Minimum	0.072	0.102	0.097	0.083	0.085	0.078	0.073	0.083246
	Maximum	0.485	0.484	0.494	0.535	0.496	0.441	0.521	1.477377
	Number of Points	4405	6276	6084	7614	4306	8062	7798	6142

From these chart and data, we could easily draw the conclusion that the realized volatility of Chinese market is quite different from the realized volatility of G7's market especially in the early 1990s. The realized volatility of Chinese market in the early 1990s is quite high and volatile since at that time, there is no limit up or down for Chinese stock market. Meanwhile, the trend of Chinese realized volatility in early 2000s is also different from the trend of G7's realized volatility. The realized volatility of G7's markets generally went down from 2003 to 2007 while the realized volatility of Chinese market went up. However, after 2008, there seems to have some kind of comovement between Chinese realized volatility and G7's realized volatility. They both seem to drop first and then recover in the recent years. However, this comovement does not seem to be strong.

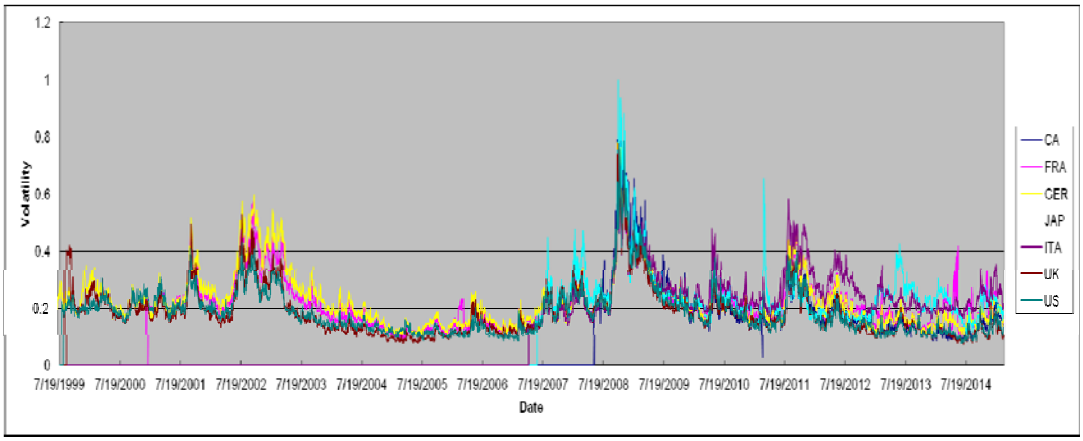
For the implied volatility, we get the implied volatility of both the call and the put and then average them correspondingly. The time ranges of these seven indices are different. Though the end dates of data of these seven index options we could get are the

same 03/06/2015, these data have different start dates. The time range of Canada is from 05/26/2008 to 03/06/2015, France from 01/05/2001 to 03/06/2015, Germany from 07/19/1999 to 03/06/2015, Japan from 06/13/2007 to 03/06/2015, Italy from 04/24/2007 to 03/06/2015, U.K. from 09/01/1999 to 03/06/2015 and U.S. from 08/11/1999 to 03/06/2015.

The following chart displays the seven time series of implied volatility.

Figure 3. Implied volatility among G7 in the whole period

This figure displays the implied volatility among G7 in the whole period.



According to this chart, financial crisis witnesses a sudden rise in stock volatility, especially in year 2008. Moreover, in year 2002, roughly during the period of dot bubble, the volatility also experiences a rise. Therefore, it might be appropriate to say that volatility will increase in the shock period. And since all volatility increase in the shock period, we could infer that in this period, the volatility of these seven indices might have higher cross correlations.

Meanwhile, we calculate and report the basic statistics of these seven time series in

the following table to show the basic information.

Table 2. Basic statistics of implied volatility among G7 in the whole period

This table shows basic statistics of implied volatility among G7 in the whole period.

	CA	FRA	GER	JAP	ITA	U.K.	U.S.
Mean	0.205	0.225	0.225	0.249	0.260	0.186	0.187
Standard Deviation	0.112	0.092	0.095	0.106	0.087	0.086	0.083
Minimum	0.026	0.091	0.107	0.113	0.125	0.074	0.079
Maximum	0.828	0.770	0.782	0.996	0.707	0.777	0.786
Number of Points	1770	3696	4080	2018	2054	4048	4063

These charts and data show that the volatility during the Crisis is much higher than the volatility in other periods and the volatility during the Crisis varies more heavily and usually moves in the same direction. These facts might infer higher cross correlations during the Crisis.

Since we are highly interested in the effect of the Financial Crisis on the cross-relationship of these seven implied volatility, the data are organized into three sub-samples. The first period is from the earliest date of the sample to 12/29/2006. Hopefully, this period could show the situation before the Crisis. The second period is from 01/01/2007 to 12/30/2011 and we wish this period could represent the period of the Crisis. The last period which is used to study the situation after the Crisis is from 01/02/2012 to 03/06/2015. Since the start dates of these seven time series are different, Canada, Japan and Italy do not have data in the first period and their start dates of the second period are their earliest dates in the sample.

Though the realized volatility has longer time range, we still use the data from 7/19/1999 which is the start date of earliest sample date for implied volatility to 09/02/2015 so that the period of the realized volatility is comparable to the period of the

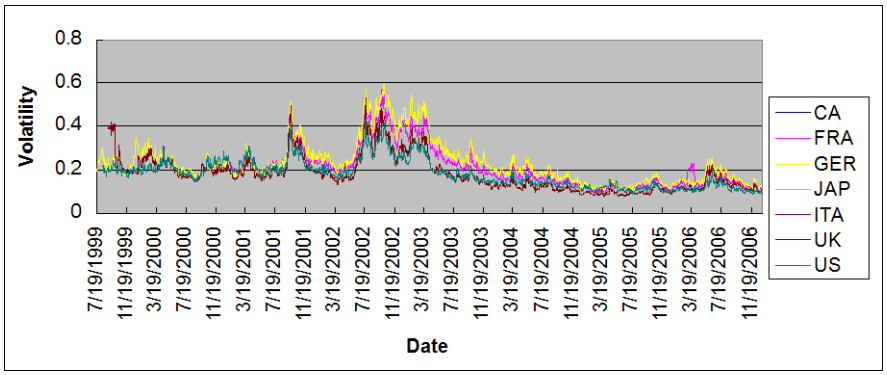
implied volatility.

Since some data are omitted in our sample of implied volatility, we graph and report the sub-periods' properties in the following charts and tables:

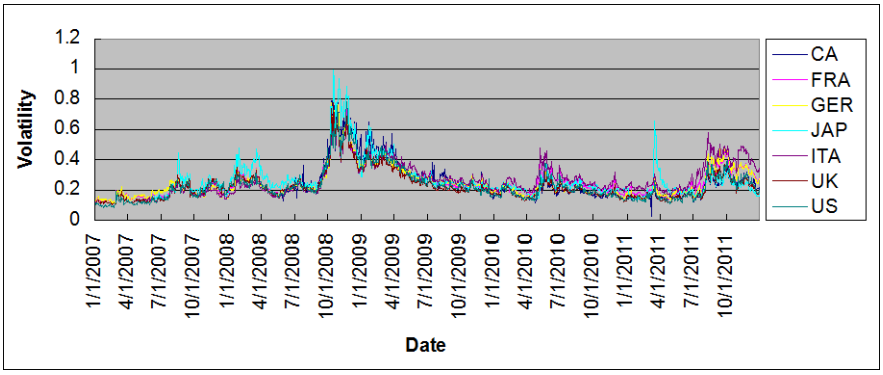
Figure 4. Implied volatility before, during and after the crisis

This figure shows the implied volatilities before the crisis, during the crisis and after the crisis. Panel 1 shows the implied volatility before the crisis; panel 2 shows the implied volatility during the crisis and panel 3 shows implied volatility after the crisis.

Panel 1: Before the crisis



Panel 2: During the crisis



Panel 3: After the crisis

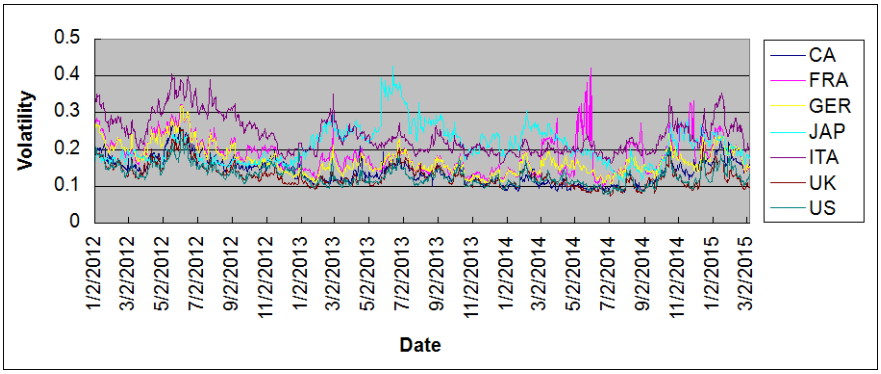


Table 3. Basic statistics of implied volatility among G7 in sub-periods

This table shows basic statistics of implied volatility among G7 in the period of before the crisis, during the crisis and after the crisis.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
Before the Crisis	Mean	NA	0.213	0.233	NA	NA	0.182	0.181
	Standard Deviation	NA	0.096	0.099	NA	NA	0.081	0.063
	Minimum	NA	0.091	0.107	NA	NA	0.077	0.087
	Maximum	NA	0.572	0.597	NA	NA	0.528	0.430
	Number of Points	0	1561	1945	0	0	1913	1928
During the Crisis	Mean	0.260	0.253	0.248	0.277	0.274	0.228	0.231
	Standard Deviation	0.126	0.097	0.100	0.124	0.103	0.095	0.105
	Minimum	0.026	0.115	0.116	0.127	0.125	0.104	0.084
	Maximum	0.828	0.770	0.782	0.996	0.707	0.777	0.786
	Number of Points	940	1305	1305	1188	1224	1305	1305
After the Crisis	Mean	0.143	0.186	0.171	0.210	0.239	0.129	0.130
	Standard Deviation	0.037	0.048	0.039	0.050	0.050	0.031	0.027
	Minimum	0.084	0.100	0.107	0.113	0.160	0.074	0.079
	Maximum	0.262	0.419	0.318	0.424	0.404	0.251	0.233
	Number of Points	830	830	830	830	830	830	830

3.Empirical analysis

3.1The dynamic of realized volatility among G7: evidence from realized volatility

3.1.1Analysis of the whole sample

In order to find out a best common factor for G7, we first calculate the $\ln(\frac{V_t}{V_{t-1}})$ correlations between any two countries.

Table 4. The correlation table (90 days) in the whole period

This table shows the correlations between any two countries of the past 90 days in the whole period. The bold figures represent the most correlated ones.

	CA	FRA	GER	JAP	ITA	U.K.	U.S.
CA	1	0.276	0.268	0.090	0.220	0.269	**0.365**
FRA	0.276	1	0.679	0.148	**0.693**	0.600	0.346
GER	0.268	**0.679**	1	0.158	0.603	0.522	0.362
JAP	0.090	0.148	**0.158**	1	0.119	0.139	0.071
ITA	0.220	**0.693**	0.603	0.119	1	0.582	0.338
U.K.	0.269	**0.600**	0.522	0.139	0.582	1	0.289
U.S.	**0.365**	0.346	0.362	0.071	0.338	0.289	1

From this table, we can find out that correlations among realized volatility are always positive. It implies the strong comovement of realized volatility among G7. In the same time, we could also find that the correlation will be larger if two countries are closer. To be more specifically, the correlations between European countries are much higher than the correlations between a European country and a non-European country and the same thing also applies to North American countries. Meanwhile, Japanese market is least correlated to other countries. This fact complies with our intuition since we know both European markets and North American markets are highly converged these days.

The bold figures represent the most correlated ones, from which we can find out the most effective common factor. From the results, we find out that French market dominates G7 in the whole period. Thereby we choose French market as the external regressor and the model is therefore the following:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + m_i \ln(\frac{v_{FRA,t}}{v_{FRA,t-1}}) + \sigma_{i,t} z_{i,t}$$
$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|z_{i,t-1}| - E[|z_{i,t-1}|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

The result of the estimates is reported in the following table.

Meanwhile, for French market, we estimate an EGARCH model without any external regressor. The mathematical expression of this model is the following:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + \sigma_{i,t} z_{i,t}$$
$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|z_{i,t-1}| - E[|z_{i,t-1}|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

The only difference between this model and the previous model is that this model does not have the external regressor. The result of the estimate is reported in the last line of following table:

Table 5. The table of 7 countries' estimated coefficients (90 days) in the whole period

This table shows the estimated coefficients of 7 countries of the past 90 days in the whole period.

	μ	m	ω	α	β	γ
CA	0.000	0.102	-0.689	-0.075	0.906	0.334
GER	0.000	0.748	-0.371	-0.062	0.951	0.633
JAP	0.000	0.048	-0.351	-0.152	0.953	0.341
ITA	0.000	0.578	-0.280	-0.153	0.963	0.444
U.K.	0.000	0.539	-0.347	-0.199	0.953	0.607
U.S.	-0.000	0.146	-0.389	-0.121	0.947	0.365
FRA	-0.000	NA	-0.393	-0.054	0.948	0.269

From the above table, we could find that the dynamics of these seven indices share a lot of common properties. For 6 countries other than France, the estimated coefficients m, which is the volatility equivalent of the beta that is routinely calculated in analyses of equity returns, are all above zero. The estimated coefficients β are all below 1.0,

ensuring the stability of the system. For estimated coefficients of France, β is above zero and γ is positive, which are consistent with the Robert Engle's EGARCH models. The volatility of realized volatility are highly one lag auto-correlated and positively affected by the latest realized errors in the mean model. In the same time, the absolute value of the error will also change the volatility of realized volatility. The difference between the absolute value of the error and the expectation of that absolute value is negatively affect the volatility of the realized volatility.

From the coefficients of the external regressor, we could conclude that the French market do represent other markets since the coefficients of the external regressor are positive. In the same time, closer country relationship does mean bigger abilities of representation. The abilities in the Europe are bigger than the abilities in the North America and the ability in Japan is the smallest.

3.1.2Analysis of sub-samples

In order to study the effect of the Crisis, we divide the whole sample into three sub-samples: before the Crisis, during the Crisis and after the Crisis. We repeat all the tests we have done here.

The following table displays the correlations in three sub-periods correspondingly:

Table 6. The correlation table (90 days)

This table shows the correlation of the past 90 days into sub-samples of before the crisis, during the crisis and after the crisis. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
Before the crisis	CA	1	0.207	0.218	0.064	0.188	0.196	**0.302**

	FRA	0.207	1	0.617	0.127	**0.646**	0.550	0.246
	GER	0.218	**0.617**	1	0.123	0.553	0.479	0.312
	JAP	0.063	**0.127**	0.123	1	0.123	0.097	0.078
	ITA	0.188	**0.646**	0.553	0.123	1	0.539	0.283
	U.K.	0.196	**0.550**	0.479	0.097	0.539	1	0.199
	U.S.	0.302	0.246	**0.312**	0.078	0.283	0.199	1
	CA	1	0.356	0.349	0.106	0.311	0.379	**0.445**
	FRA	0.356	1	0.756	0.186	**0.809**	0.693	0.440
	GER	0.349	**0.756**	1	0.203	0.683	0.581	0.420
During the crisis	JAP	0.106	0.186	**0.203**	1	0.129	0.175	0.054
	ITA	0.311	**0.809**	0.683	0.129	1	0.675	0.417
	U.K.	0.379	**0.693**	0.581	0.175	0.675	1	0.398
	U.S.	**0.445**	0.440	0.420	0.054	0.417	0.398	1
	CA	1	0.268	0.217	0.120	0.106	0.225	**0.353**
	FRA	0.268	1	**0.617**	0.092	0.501	0.497	0.305
	GER	0.217	**0.617**	1	0.110	0.498	0.477	0.323
After the crisis	JAP	0.120	0.092	0.110	1	0.082	**0.142**	0.101
	ITA	0.106	**0.501**	0.498	0.082	1	0.469	0.242
	U.K.	0.225	**0.497**	0.477	0.142	0.469	1	0.224
	U.S.	**0.353**	0.305	0.323	0.101	0.242	0.224	1

From this table, we can find out that correlations among realized volatilities are always positive in three time periods, mostly reach their peaks during the Crisis though exceptions do exist. In the same time, the correlation will be larger if two countries are closer.

The bold figures represent the most correlated ones, from which we pick up the most effective common factor. From the results, we find out that French market dominates G7 in all three periods though the importance decrease slightly. Thereby, we use the models we have used before.

We report the estimated results for 7 countries for all three periods in the following table:

Table 7. The table of 7 Countries' Estimated Coefficients (90 Days)

This table shows the estimated coefficients of 6 countries other than France of the past 90 days for the periods of before the crisis, during the crisis and after the crisis.

In the same time, we report the estimated results for France in all these three periods in the following table. It shows the estimated coefficients of France of the past 90 days for the periods of before the crisis, during the crisis and after the crisis.

		μ	m	ω	α	β	γ
Before the Crisis	CA	0.000	0.066	-0.761	-0.094	0.897	0.228
	GER	0.000	0.731	-0.286	-0.023	0.967	0.308
	JAP	-0.000	0.036	-0.366	-0.098	0.951	0.231
	ITA	0.000	0.544	-0.425	-0.137	0.943	0.504
	U.K.	0.000	0.434	-0.405	-0.127	0.944	0.705
	U.S.	-0.000	0.092	-0.233	-0.159	0.968	0.250
	FRA	-0.000	NA	-0.318	-0.054	0.957	0.293
In the Crisis	CA	0.000	0.132	-0.500	-0.088	0.931	0.447
	GER	0.000	0.810	-0.490	-0.153	0.940	0.700
	JAP	0.000	0.065	-0.313	-0.287	0.959	0.530
	ITA	0.000	0.691	-0.239	-0.200	0.968	0.498
	U.K.	0.000	0.677	-0.362	-0.294	0.954	0.577
	U.S.	0.000	0.221	-0.378	-0.149	0.950	0.465
	FRA	0.000	NA	-0.390	-0.085	0.949	0.340
After the Crisis	CA	0.000	0.102	-0.689	-0.075	0.906	0.334
	GER	0.000	0.748	-0.371	-0.062	0.951	0.633
	JAP	0.000	0.048	-0.351	-0.152	0.953	0.341
	ITA	0.000	0.578	-0.280	-0.153	0.963	0.444
	U.K.	0.000	0.539	-0.347	-0.199	0.953	0.607
	U.S.	0.000	0.146	-0.389	-0.121	0.947	0.365
	FRA	-0.000	NA	-2.824	-0.104	0.616	-0.007

For 6 countries other than France, the estimated coefficients m, which is the volatility equivalent of the beta that is routinely calculated in analyses of equity returns, are all above zero for periods of before the crisis, in the crisis and after the crisis. The estimated coefficients β are all between o and 1, ensuring the stability of the system for all three sub-periods. For estimated coefficients of France, β is all above zero and γ is positive except for the period of after the crisis, which are almost consistent with the Robert Engle's EGARCH models.

From this table, we can find out that the conclusions we have drawn for the whole period apply to the three periods as well. In the same time, we can also find out that the

realized volatility increases a lot during the crisis.

3.2The dynamics of correlations among G7 and China: evidence from realized volatility

3.2.1Analysis of the whole sample

In order to study the dynamics of realized volatility of China, we first calculate the correlations between Chinese realized volatility and G7's realized volatility. We report the calculation result in the following table:

Table 8. Correlation between the realized volatility of Chinese market and the ones of G7's markets (90 days) in the whole period

This table displays the correlation between the realized volatility of Chinese market and the ones of G7's markets of the past 90 days in the whole period.

CA	FRA	GER	JAP	ITA	U.K.	U.S.
0.042	0.038	0.031	0.028	0.046	0.053	0.041

This table shows that though positive correlations exist between the realized volatility of Chinese markets and the realized volatility of G7's markets, these correlations are much smaller than the correlations within G7. It might because that Chinese market is relatively isolated and the volatility comovement is thereby week.

Since China is most correlated to U.K., we choose U.K. as the external regressor. The model is thereby the following:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + m_i \ln(\frac{v_{uk,t}}{v_{uk,t-1}}) + \sigma_{i,t} z_{i,t}$$

$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|z_{i,t-1}| - E[|z_{i,t-1}|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

The explanation of this model is exactly the same as the explanation before.

The estimated result is reported in the following table:

Table 9. The table of estimated coefficients for China (90 days) in the whole period

This table shows estimated coefficients for China of the past 90 days in the whole period.

μ	m	ω	α	β	γ
-0.000	0.005	-0.252	-0.072	0.967	0.085

This table shows that the dynamics of China is basically as the dynamics of G7. However, the ability of the common factor to represent the realized volatility of China is much weaker. This accords with our correlation calculation. For estimated coefficients of China, the estimated coefficient m, which is the volatility equivalent of the beta that is routinely calculated in analyses of equity returns, is above zero. The estimated coefficients β is between o and 1, ensuring the stability of the system, which is consistent with the Robert Engle's EGARCH models.

3.2.2Analysis of three Sub-samples

In order to study how the crisis affect the dynamics of Chinese implied volatility, we divide the whole sample into three sub-samples just as we have done before.

We first calculate the correlations as we usually do and report them in the following tables:

Table 10. Correlation between the realized volatility of Chinese market and the ones of G7's markets (90 days)

This table shows the correlation between the realized volatility of Chinese market and the ones of G7's markets of the past 90 days for the periods of before the crisis, during the crisis and after the crisis.

	CA	FRA	GER	JAP	ITA	U.K.	U.S.
Before the Crisis	-0.007	0.002	-0.018	0.010	0.007	0.000	-0.010
During the Crisis	0.187	0.127	0.127	0.073	0.140	0.140	0.162
After the Crisis	-0.011	0.001	0.010	-0.006	0.008	0.087	-0.026

Though the correlations before and after the Crisis are really small, sometimes even negative, the correlations during the Crisis are relatively much higher and strictly positive. The increases of correlations during the Crisis are really significant just as what we have found for G7.

The next table reports the estimated coefficients for China using the EGARCH model.

Table 11. The table of estimated coefficients for China (90 days)

This table shows estimated coefficients for China of the past 90 days for the periods of before the crisis, during the crisis and after the crisis.

	μ	m	ω	α	β	γ
Before the Crisis	0	-0.008	-0.384	-0.08	0.951	0.135
During the Crisis	0	0.021	-0.246	-0.082	0.968	0.114
After the Crisis	0	0.002	-0.105	0	0.985	-0.131

Though other parameters do have some significant changes such as γ, we are more interested in the change of m, the coefficients of the external regressor since they show how the correlations change over time. For the results of sub-periods, the estimated coefficient m, which is the volatility equivalent of the beta that is routinely calculated in analyses of equity returns, is above zero except the period of before the crisis. The estimated coefficients β is between o and 1, ensuring the stability of the system, which is consistent with the Robert Engle's EGARCH models. The result here accords to the

result we have gotten in the last part. The correlations between Chinese market and G7's markets do strengthen a lot during the Crisis.

3.3The dynamics of correlations among G7: evidence from implied volatility

3.3.1Analysis of the whole sample

As usual, we first calculate the $\ln(\frac{V_t}{V_{t-1}})$ correlations between any two countries to get a rough idea of the whole picture and to find out the best common factor. The result are reported in the following table:

Table 12. The correlation table of implied volatility among G7 in the whole period

This table shows the correlations between any two countries in the whole period. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
The Whole Period	CA	1	0.191	0.263	0.053	0.168	0.273	**0.399**
	FRA	0.191	1	**0.683**	0.199	0.535	0.658	0.378
	GER	0.263	0.683	1	0.275	0.688	**0.758**	0.460
	JAP	0.053	0.199	0.275	1	**0.385**	0.276	0.052
	ITA	0.168	0.535	**0.688**	0.385	1	0.622	0.294
	U.K.	0.273	0.658	**0.758**	0.276	0.622	1	0.433
	U.S.	0.399	0.378	**0.460**	0.052	0.294	0.433	1

From this table, we could also find out the correlations between European countries are much higher than the correlations between a European country and a non-European country. The same thing seems to be true for North American as well though some anomalies do exist. We conjecture that the lack of enough data points for Canada would be the main reason for these anomalies. During the Crisis, the correlations related to

Canada are extremely lower than the correlations unrelated to Canada. This might result from the possibility that the missing data are in the period when the correlations are extremely high. Therefore, the correlations related to Canada we have calculated will be lower than the actual correlations. This could possibly explain why during the Crisis the correlation of U.S. and Canada is not the highest in all correlations related to U.S. at that time. The result here is thereby quite similar to the result we have gotten using realized volatility. However, the correlations here are bigger than the correlations for the realized volatility. Since some papers point out that the information of implied volatility consists of both the information of realized volatility and the information of future expectation, it seems that the future expectation is more correlated than the realized volatility.

The bold figures represent the most correlated ones, from which we pick up the most effective common factor. The results show that the implied volatility of German market seems to be most correlated with the implied volatility of other G6 markets and thereby we choose it as the best common factor. This is different from the realized volatility where the implied volatility of France is the best common factor. Thereby the mathematical expression of the model here is the following:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + m_i \ln(\frac{v_{GER,t}}{v_{GER,t-1}}) + \sigma_{i,t} z_{i,t}$$
$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|z_{i,t-1}| - E[|z_{i,t-1}|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

Meanwhile, we use the EGARCH model without any external regressor to model the German market. The mathematical expression of this model is the following:

$$\ln(\frac{v_{i,t}}{v_{i,t-1}}) = \mu_i + \sigma_{i,t} z_{i,t}$$
$$\ln(\sigma_{i,t}^2) = \omega_i + \alpha_i(|z_{i,t-1}| - E[|z_{i,t-1}|]) + \beta_i \ln(\sigma_{i,t-1}^2) + \gamma_i z_{i,t-1}$$

The explanation of these models is the same as before.

We report the estimated coefficients of 7 countries in the following table:

Table 13. The table of 7 countries' estimated coefficients (implied volatility)

This table shows the estimated coefficients of 7 countries.

	μ	m	ω	α	β	γ
CA	0.001	0.481	-1.289	0.186	0.736	0.458
FRA	-0.000	0.906	-1.364	0.064	0.800	0.482
JAP	-0.003	0.201	-0.248	0.002	0.953	0.198
ITA	-0.000	0.579	-0.729	0.047	0.887	0.278
U.K.	-0.001	0.869	-0.512	0.001	0.920	0.260
U.S.	-0.000	0.515	-0.478	0.122	0.916	0.191
GER	-0.002	NA	-0.232	0.106	0.960	0.096

Most conclusions we have made for realized volatility also hold here while differences do exist: For realized volatility, the symbol of α is negative while the symbol here is positive.

As usual, we are more interested in m than other parameters. Here, the coefficients of the external regressor are positive and bigger if countries' relation is closer which are same as we have concluded before. Moreover ms here are bigger than ms for realized volatility which accords with the result of the correlation analysis we have done in this part.

3.3.2Analysis of the sub-samples

We repeat our study here for all three sub-samples as before.

The correlations among G7 are reported in the following table:

Table 14. The correlation table of implied volatility among G7

This table displays the correlation table of implied volatility among G7 for the periods of before the crisis, during the crisis and after the crisis. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
Before the Crisis	CA	NA	NA	NA	NA	NA	NA	NA
	FRA	NA	1	0.621	NA	NA	**0.660**	0.361
	GER	NA	**0.621**	1	NA	NA	0.602	0.392
	JAP	NA	NA	NA	NA	NA	NA	NA
	ITA	NA	NA	NA	NA	NA	NA	NA
	U.K.	NA	**0.660**	0.602	NA	NA	1	0.349
	U.S.	NA	0.361	**0.392**	NA	NA	0.349	1
During the Crisis	CA	1	0.260	0.261	0.061	0.186	0.282	**0.353**
	FRA	0.260	1	**0.910**	0.323	0.707	0.881	0.507
	GER	0.261	**0.910**	1	0.330	0.714	0.878	0.511
	JAP	0.061	0.323	0.330	1	**0.441**	0.332	0.063
	ITA	0.186	0.707	**0.714**	0.441	1	0.657	0.318
	U.K.	0.282	**0.881**	0.878	0.332	0.657	1	0.497
	U.S.	0.353	0.507	**0.511**	0.063	0.318	0.497	1
After the Crisis	CA	1	0.148	0.277	0.029	0.126	0.279	**0.515**
	FRA	0.148	1	**0.548**	0.058	0.382	0.466	0.270
	GER	0.277	0.548	1	0.152	0.639	**0.832**	0.482
	JAP	0.029	0.058	0.152	1	**0.228**	0.167	0.027
	ITA	0.126	0.382	**0.639**	0.228	1	0.566	0.245
	U.K.	0.279	0.466	**0.832**	0.167	0.566	1	0.456
	U.S.	**0.515**	0.270	0.482	0.027	0.245	0.456	1

Except Canada, all other countries seem to roughly follow the pattern that the correlations reach their peaks during the Crisis. The reason why Canada does not follow this pattern might also be that we do not have large enough sample of Canada as well. However, we preserve our opinions.

The bold figures represent the most correlated ones, from which we pick up the most effective common factor. From the results, we find out that before the Crisis, the French market dominates the European Market but the German market gains more and more influence during and after the Crisis and overall Germany is most influential among G7. Thereby, we still estimate an EGARCH model with Germany as an external regressor for

G7 other than Germany and estimate an EGARCH model without external regressor for Germany.

We report the result of estimates in the following tables:

Table 15. The table of 7 countries' estimated coefficients (implied volatility)

This table shows the estimated coefficients of 7 countries for the periods of before the crisis, during the crisis and after the crisis.

		μ	m	ω	α	β	γ
	CA	NA	NA	NA	NA	NA	NA
	FRA	-0.001	0.689	-2.924	0.063	0.566	0.529
	JAP	NA	NA	NA	NA	NA	NA
Before the Crisis	ITA	NA	NA	NA	NA	NA	NA
	U.K.	-0.001	0.717	-1.021	0.076	0.835	0.322
	U.S.	0.001	0.420	-1.009	0.119	0.827	0.176
	GER	-0.001	NA	-0.388	0.086	0.933	0.151
	CA	0.001	0.564	-1.095	0.213	0.767	0.471
	FRA	0.000	0.964	-2.436	0.027	0.677	0.468
	JAP	-0.003	0.301	-0.281	0.003	0.945	0.226
In the Crisis	ITA	-0.000	0.664	-1.138	0.036	0.820	0.376
	U.K.	-0.001	0.939	-2.647	-0.110	0.614	0.467
	U.S.	-0.002	0.633	-0.415	0.043	0.924	0.305
	GER	-0.002	NA	-0.151	0.161	0.974	0.017
	CA	0.001	0.388	-1.841	0.123	0.644	0.457
	FRA	0.000	0.975	-0.753	0.469	0.857	0.609
	JAP	-0.004	0.105	-1.060	-0.006	0.811	0.184
After the Crisis	ITA	-0.001	0.476	-0.613	0.029	0.908	0.185
	U.K.	-0.001	0.906	-0.093	-0.007	0.986	0.087
	U.S.	-0.001	0.552	-0.489	0.219	0.912	0.109
	GER	-0.004	NA	-0.390	0.107	0.930	0.075

For a rough sight, the basic properties in all these three periods do not change too much. However, since we have special interest in the coefficients of external regressor, we report them in the following table as usual.

For the results of implied volatility, the results are perfect consistent with Robert Engle's EGARCH models. This shows pervasiveness of the EGARCH model, which can

be used both in the stock market and different country market for implied volatilities.

3.3.3 Implication

This part shows that though the realized volatility and the implied volatility are not the same, their dynamics share a lot of common properties. We know that index option is heavily regulated or even does not exist in some countries i.e. China and thereby the implied volatility is unavailable. We could use this result to infer the dynamics of implied volatility from the dynamics of realized volatility which is always available.

4.Robustness test

4.1 Robustness test for realized volatility among G7

In the previous part, we use 90 days realized volatility to do the tests. Here we repeat all the tests which we have done for realized volatility with 60 days, 120 days and 180 days realized volatility to do robustness tests. The correlations among G7 of the last 60 days and 120 days is represented in appendix.

Table 16. The correlations among G7 (180 Days)

This table shows the correlations among G7 of the past 180 days for the periods of before the crisis, during the crisis and after the crisis. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
In the Whole Period	CA	1	0.276	0.253	0.097	0.218	0.238	**0.367**
	FRA	0.276	1	0.561	0.138	**0.625**	0.54	0.32
	GER	0.253	**0.561**	1	0.14	0.524	0.451	0.355
	JAP	0.097	0.138	**0.14**	1	0.101	0.121	0.079
	ITA	0.218	**0.625**	0.524	0.101	1	0.567	0.313
	U.K.	0.238	0.54	0.451	0.121	**0.567**	1	0.305
	U.S.	**0.367**	0.32	0.355	0.079	0.313	0.305	1
Before the Crisis	CA	1	0.218	0.18	0.066	0.188	0.153	**0.293**
	FRA	0.218	1	0.516	0.129	**0.566**	0.472	0.266

	GER	0.18	0.516	1	0.086	**0.53**	0.404	0.278
	JAP	0.066	**0.129**	0.086	1	0.104	0.07	0.049
	ITA	0.188	**0.566**	0.53	0.104	1	0.508	0.217
	U.K.	0.153	0.472	0.404	0.07	**0.508**	1	0.246
	U.S.	**0.293**	0.266	0.278	0.049	0.217	0.246	1
During the Crisis	CA	1	0.342	0.353	0.153	0.304	0.35	**0.475**
	FRA	0.342	1	0.641	0.168	**0.746**	0.668	0.385
	GER	0.353	**0.641**	1	0.211	0.541	0.547	0.448
	JAP	0.153	0.168	**0.211**	1	0.136	0.171	0.101
	ITA	0.304	**0.746**	0.541	0.136	1	0.681	0.433
	U.K.	0.35	0.668	0.547	0.171	**0.681**	1	0.381
	U.S.	**0.475**	0.385	0.448	0.101	0.433	0.381	1
After the Crisis	CA	1	0.251	0.178	0.04	0.06	0.189	**0.289**
	FRA	0.251	1	**0.396**	0.062	0.331	0.342	0.216
	GER	0.178	0.396	1	0.035	**0.442**	0.295	0.219
	JAP	0.04	0.062	0.035	1	-0.03	**0.101**	0.064
	ITA	0.06	0.331	**0.442**	-0.03	1	0.385	0.102
	U.K.	0.189	0.342	0.295	0.101	**0.385**	1	0.215
	U.S.	**0.289**	0.216	0.219	0.064	0.102	0.215	1

From this table, we also find out that correlations among realized volatiities are always positive, mostly reach their peaks during the Crisis though exceptions do exist and will be larger if two countries are closer which are just the same as the correlations among implied ones. Moreover, we can also find out that correlations here are much smaller than correlations among implied ones. All these results coincide with the results we have gotten from 90 days realized volatility.

In all these three situations, France dominate among G7 and the importance decrease slightly over the time. It coincides with the results of 90 days realized volatility.

Since we are mainly interested in the coefficients of the external regressor, we report these coefficients here and skip others for the sake of simplicity.

Table 17. The table of coefficients of external regressor (FRA) (180 days)

This table shows the coefficients of external regressor of France of the pattern of and 180 days for the

whole period and sub-periods of before the crisis, during the crisis and after the crisis. The coefficients of the last 60 days and 120 days is represented in appendix.

		In the Whole Period	Before the Crisis	In the Crisis	After the Crisis
180 Days	CA	0.120	0.113	0.128	0.130
	GER	0.599	0.581	0.699	0.479
	JAP	0.047	0.042	0.070	0.016
	ITA	0.447	0.410	0.598	0.235
	U.K.	0.409	0.316	0.594	0.148
	U.S.	0.119	0.083	0.222	0.070

All these situations are generally follow the pattern of 90 days.

Thereby, we conclude that our results about realized volatility using 90 days calculation among G7 pass the robustness test.

4.2 Robustness test for realized volatility of Chinese market

As before, we first calculate the correlations for the three situations and report them in the following table.

Table 18. Correlation between the realized volatility of Chinese Market and the ones of G7's markets

This table shows the correlation between the realized volatility of Chinese market and the ones of G7's markets for the whole period and sub-periods of before the crisis, during the crisis and after the crisis, for robustness test of 180 days. The correlation of the last 60 days and 120 days is represented in appendix.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
180 Days	In the Whole Period	0.033	0.037	0.046	0.023	0.029	0.045	0.041
	Before the Crisis	-0.033	-0.009	0.010	0.009	0.003	-0.008	-0.027
	During the Crisis	0.129	0.079	0.078	0.072	0.053	0.115	0.137
	After the Crisis	0.093	0.103	0.105	-0.036	0.077	0.095	0.042

These correlations roughly coincide with the result of 90 days since the correlations before and after the Crisis are generally very small though exceptions do appear in some cases and the correlations during the Crisis are relatively higher and strictly positive.

The result of estimates is reported in the following table:

Table 19. Estimated coefficients for Chinese market (U.K.)

This table shows the estimated coefficients for Chinese market for the whole period and sub-periods of before the crisis, during the crisis and after the crisis, for robustness test of 180 days. The coefficients of the last 60 days and 120 days is represented in appendix.

		In the Whole Period	Before the Crisis	During the Crisis	After the Crisis
180 Days	μ	-0.000	-0.000	-0.000	-0.000
	m	0.004	-0.009	0.024	-0.002
	ω	-0.753	-0.994	-0.471	-1.138
	α	-0.025	0.020	-0.105	0.115
	β	0.918	0.894	0.948	0.872
	γ	0.231	0.290	0.171	0.139

These results also coincide with the 90 days situation.

Thereby, our result of realized volatility for China pass the robustness test.

5.Conclusion

In this paper, we use the EGARCH/DCC models to study the dynamics of correlations among international stock markets for both realized and implied volatilities. We find that there do exist positive correlations among G7 countries' volatility and with closer country relationship, the correlation of volatility will be bigger. Also, it is possible to find out a common factor which could represent the volatility in other countries more or less. Further, the recent crisis not only increase the volatilities a lot but also increase the

correlations of both realized and implied volatilities. Thirdly, though there exists difference between the realized volatility and the implied volatility, the dynamics of them generally have the same structure. Finally, the realized volatility of Chinese market do not significantly correlate to the realized volatility of G7's , however, during the 2008 crisis, the correlation is strengthened as well.

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Appendix A: Robustness Test Result of Realized Volatility for 60 days and 120 days

Table A1. The Correlations among G7 (60 Days)

This table shows the correlations among G7 of the past 60 days for the periods of before the crisis, during the crisis and after the crisis. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
In the Whole Period	CA	1	0.258	0.267	0.068	0.225	0.246	**0.376**
	FRA	0.258	1	**0.696**	0.119	0.694	0.604	0.315
	GER	0.267	**0.696**	1	0.141	0.631	0.549	0.315
	JAP	0.068	0.119	**0.140**	1	0.084	0.130	0.067
	ITA	0.224	**0.694**	0.631	0.084	1	0.585	0.293
	U.K.	0.246	**0.604**	0.549	0.130	0.585	1	0.286
	U.S.	**0.376**	0.315	0.315	0.067	0.293	0.286	1
Before the Crisis	CA	1	0.210	0.226	0.040	0.179	0.190	**0.258**
	FRA	0.210	1	**0.665**	0.114	0.646	0.574	0.259
	GER	0.226	**0.665**	1	0.110	0.610	0.505	0.247
	JAP	0.040	**0.114**	0.110	1	0.076	0.111	0.093
	ITA	0.179	**0.646**	0.610	0.076	1	0.573	0.243
	U.K.	0.190	**0.574**	0.505	0.111	0.573	1	0.232
	U.S.	0.258	**0.259**	0.247	0.093	0.243	0.232	1
During the Crisis	CA	1	0.373	0.345	0.102	0.313	0.355	**0.514**
	FRA	0.373	1	0.747	0.152	**0.787**	0.668	0.396
	GER	0.345	**0.747**	1	0.192	0.691	0.596	0.397
	JAP	0.102	0.152	**0.192**	1	0.103	0.147	0.058
	ITA	0.313	**0.787**	0.691	0.103	1	0.656	0.378
	U.K.	0.355	**0.668**	0.596	0.147	0.656	1	0.369
	U.S.	**0.514**	0.396	0.397	0.058	0.378	0.369	1
After the Crisis	CA	1	0.155	0.220	0.070	0.165	0.184	**0.370**
	FRA	0.155	1	**0.649**	0.053	0.595	0.537	0.248
	GER	0.220	**0.649**	1	0.087	0.542	0.546	0.272
	JAP	0.070	0.053	0.087	1	0.054	**0.135**	0.038
	ITA	0.165	**0.595**	0.542	0.054	1	0.458	0.201
	U.K.	0.184	0.537	**0.546**	0.135	0.458	1	0.221
	U.S.	**0.370**	0.248	0.272	0.038	0.201	0.221	1

Table A2. The Correlations among G7 (120 Days)

This table shows the correlations among G7 of the past 120 days for the periods of before the crisis, during the crisis and after the crisis. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
In the Whole Period	CA	1	0.250	0.243	0.082	0.214	0.250	**0.353**

	FRA	0.250	1	0.645	0.099	**0.664**	0.604	0.320
	GER	0.243	**0.645**	1	0.154	0.577	0.513	0.345
	JAP	0.082	0.099	**0.154**	1	0.074	0.130	0.0720
	ITA	0.214	**0.664**	0.577	0.074	1	0.584	0.293
	U.K.	0.250	**0.604**	0.513	0.130	0.584	1	0.270
	U.S.	**0.353**	0.320	0.345	0.072	0.293	0.270	1
Before the Crisis	CA	1	0.176	0.176	0.053	0.179	0.178	**0.269**
	FRA	0.176	1	0.594	0.032	**0.608**	0.562	0.225
	GER	0.176	**0.594**	1	0.083	0.532	0.460	0.265
	JAP	0.053	0.032	**0.083**	1	0.007	0.046	0.071
	ITA	0.179	**0.608**	0.532	0.007	1	0.519	0.204
	U.K.	0.178	**0.562**	0.460	0.046	0.519	1	0.211
	U.S.	**0.269**	0.225	0.265	0.071	0.204	0.211	1
During the Crisis	CA	1	0.339	0.342	0.102	0.302	0.350	**0.441**
	FRA	0.339	1	**0.708**	0.172	0.786	0.697	0.423
	GER	0.342	**0.708**	1	0.221	0.668	0.610	0.431
	JAP	0.102	0.172	0.221	1	0.128	**0.184**	0.055
	ITA	0.302	0.786	0.668	0.128	1	**0.694**	0.397
	U.K.	0.350	**0.697**	0.610	0.184	0.694	1	0.360
	U.S.	**0.441**	0.423	0.431	0.055	0.397	0.360	1
After the Crisis	CA	1	0.223	0.173	0.103	0.092	0.216	**0.357**
	FRA	0.223	1	**0.574**	0.038	0.437	0.477	0.211
	GER	0.173	**0.574**	1	0.107	0.407	0.393	0.255
	JAP	0.103	0.038	0.107	1	0.062	**0.173**	0.116
	ITA	0.092	0.437	0.407	0.062	1	**0.469**	0.158
	U.K.	0.216	**0.477**	0.393	0.173	0.469	1	0.164
	U.S.	**0.357**	0.211	0.255	0.116	0.158	0.164	1

Table A3. The table of coefficients of external regressor (FRA)

This table shows the coefficients of external regressor of France of the pattern of and 60 days and 120 days for the whole period and sub-periods of before the crisis, during the crisis and after the crisis.

		In the Whole Period	Before the Crisis	In the Crisis	After the Crisis
60 Days	CA	0.098	0.083	0.142	0.083
	GER	0.803	0.761	0.864	0.792
	JAP	0.043	0.037	0.064	0.043
	ITA	0.642	0.627	0.724	0.489
	U.K.	0.617	0.525	0.744	0.461
	U.S.	0.108	0.084	0.145	0.098
120 Days	CA	0.109	0.089	0.118	0.130
	GER	0.723	0.702	0.774	0.684
	JAP	0.047	0.050	0.044	0.036
	ITA	0.552	0.529	0.628	0.313
	U.K.	0.503	0.487	0.641	0.254
	U.S.	0.138	0.098	0.222	0.109

Table A4. Correlation between the Realized Volatility of Chinese Market and the Ones of G7's Markets

This table shows the correlation between the realized volatility of Chinese market and the ones of G7's markets for the whole period and sub-periods of before the crisis, during the crisis and after the crisis, for robustness test of 60 days and 120 days.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
60 Days	In the Whole Period	0.027	0.042	0.047	0.010	0.041	0.055	0.044
	Before the Crisis	-0.012	0.010	0.021	-0.017	-0.001	0.011	0.001
	During the Crisis	0.110	0.093	0.095	0.059	0.124	0.120	0.102
	After the Crisis	0.025	0.061	0.049	-0.019	0.033	0.097	0.078
120 Days	In the Whole Period	0.018	0.032	0.035	0.026	0.021	0.050	0.030
	Before the Crisis	-0.047	-0.002	0.008	-0.000	-0.013	0.018	-0.029
	During the Crisis	0.146	0.101	0.113	0.044	0.097	0.089	0.142
	After the Crisis	0.031	0.018	-0.024	0.068	-0.015	0.093	-0.007

Table A5. Estimated Coefficients for Chinese Market (U.K.)

This table shows the estimated coefficients for Chinese market for the whole period and sub-periods of before the crisis, during the crisis and after the crisis, for robustness test of 60 days and 120 days.

		In the Whole Period	Before the Crisis	During the Crisis	After the Crisis
60 Days	μ	-0.000	-0.000	-0.000	-0.000
	m	0.003	-0.009	0.012	0.030
	ω	-0.095	-0.087	-0.228	-0.139
	α	-0.062	-0.070	-0.092	-0.000
	β	0.985	0.987	0.965	0.980
	γ	-0.012	-0.021	0.010	-0.114
120 Days	μ	0.000	-0.000	-0.000	0.000
	m	0.005	-0.009	0.028	0.020
	ω	-0.394	-0.456	-0.506	-1.869
	α	-0.095	-0.110	-0.119	0.073
	β	0.952	0.946	0.939	0.766
	γ	0.149	0.151	0.248	0.080

Appendix B: Robustness Test for Implied Volatility among G7

We standardize the data and then run the regressions which we have used before to do the robustness

tests. The method we have used to standardize is first subtracting every time series by its mean and then dividing the resulting series by its standard deviation.

We first calculate the correlation as we usually do.

Table B1. The Correlations in the Whole Period among G7

This table shows the correlations among G7 for the whole period and sub-periods of before the crisis, during the crisis and after the crisis. The bold figures represent the most correlated ones.

		CA	FRA	GER	JAP	ITA	U.K.	U.S.
In the Whole Period	CA	1	0.191	0.263	0.053	0.168	0.273	**0.399**
	FRA	0.191	1	**0.683**	0.199	0.535	0.658	0.378
	GER	0.263	0.683	1	0.275	0.688	**0.758**	0.460
	JAP	0.053	0.199	0.275	1	**0.385**	0.276	0.052
	ITA	0.168	0.535	**0.688**	0.385	1	0.622	0.294
	U.K.	0.273	0.658	**0.758**	0.276	0.622	1	0.433
	U.S.	0.399	0.378	**0.460**	0.052	0.294	0.433	1
Before the Crisis	CA	NA	NA	NA	NA	NA	NA	NA
	FRA	NA	1	0.621	NA	NA	**0.660**	0.361
	GER	NA	**0.621**	1	NA	NA	0.602	0.392
	JAP	NA	NA	NA	NA	NA	NA	NA
	ITA	NA	NA	NA	NA	NA	NA	NA
	U.K.	NA	**0.660**	0.602	NA	NA	1	0.349
	U.S.	NA	0.361	**0.392**	NA	NA	0.349	1
During the Crisis	CA	1	0.260	0.261	0.061	0.186	0.282	**0.353**
	FRA	0.260	1	**0.910**	0.323	0.707	0.881	0.507
	GER	0.261	**0.910**	1	0.330	0.714	0.878	0.511
	JAP	0.061	0.323	0.330	1	**0.441**	0.332	0.063
	ITA	0.186	0.707	**0.714**	0.441	1	0.657	0.318
	U.K.	0.282	**0.881**	0.878	0.332	0.657	1	0.497
	U.S.	0.353	0.507	**0.511**	0.063	0.318	0.497	1
After the Crisis	CA	1	0.148	0.277	0.029	0.126	0.279	**0.515**
	FRA	0.148	1	**0.548**	0.058	0.382	0.466	0.270
	GER	0.277	0.548	1	0.152	0.639	**0.832**	0.482
	JAP	0.029	0.058	0.152	1	**0.228**	0.167	0.027
	ITA	0.126	0.382	**0.639**	0.228	1	0.566	0.245
	U.K.	0.279	0.466	**0.832**	0.167	0.566	1	0.456
	U.S.	**0.515**	0.270	0.482	0.027	0.245	0.456	1

The correlations here also share the properties with the correlations of original tests we have done before. Still, we could find out that Germany dominates the market in the whole period and this

domination is gained gradually. Meanwhile, with closer relationship among countries, the standardized implied volatility have bigger correlation. As before, we still pick up Germany as the new external regressor. For Germany, we estimate an EGARCH model without any external regressor.

The results of estimates are displayed in the following tables and since a lot of countries are unsolvable in the whole period, we do not post the results for the whole period here:

Table B2. The table of 6 Countries' Estimated Coefficients among G7 (Implied Volatility) (GER)

This table shows the estimated coefficients of 6 countries other than Germany for the periods of before the crisis, during the crisis and after the crisis.

		μ	m	ω	α	β	γ
Before the Crisis	CA	NA	NA	NA	NA	NA	NA
	FRA	-0.010	0.585	-0.644	0.063	0.566	0.529
	JAP	NA	NA	NA	NA	NA	NA
	ITA	NA	NA	NA	NA	NA	NA
	U.K.	-0.008	0.670	-0.123	0.076	0.835	0.322
	U.S.	0.010	0.364	-0.095	0.119	0.827	0.176
In the Crisis	CA	0.010	0.304	-0.082	0.213	0.767	0.471
	FRA	0.002	0.818	-0.740	0.027	0.677	0.468
	JAP	Unsolvable	Unsolvable	Unsolvable	Unsolvable	Unsolvable	Unsolvable
	ITA	-0.012	0.707	-0.109	0.036	0.820	0.376
	U.K.	-0.013	0.878	-0.547	-0.110	0.614	0.467
	U.S.	-0.025	0.548	-0.013	0.043	0.924	0.305
After the Crisis	CA	0.006	0.209	-0.294	0.123	0.644	0.457
	FRA	0.008	0.827	0.040	0.547	0.861	0.684
	JAP	-0.052	0.083	-0.097	-0.006	0.811	0.184
	ITA	-0.015	0.507	-0.087	0.029	0.908	0.185
	U.K.	-0.005	0.847	-0.015	-0.007	0.986	0.087
	U.S.	-0.012	0.477	-0.025	0.219	0.912	0.109

Table B3. The table of German Market's Estimated Coefficients (Implied Volatility)

This table shows the estimated coefficients of German market for the periods of before the crisis, during the crisis and after the crisis.

	μ	ω	α	β	γ
Before the Crisis	-0.021	-0.015	0.087	0.938	0.142
In the Crisis	-0.028	-0.007	0.161	0.974	0.017

After the Crisis	-0.059	-0.002	0.107	0.930	0.075

As usual, we particularly report the table of coefficients of external regressor in the following table:

Table B4. The table of coefficients of external regressor (Implied Volatility) (GER)

This table shows the coefficients of external regressor of Germany for the periods of before the crisis, during the crisis and after the crisis.

	Before the Crisis	In the Crisis	After the Crisis
CA	NA	0.304389582	0.209094591
FRA	0.584519139	0.817540258	0.827327253
JAP	NA	Unsolvable	0.083
ITA	NA	0.707	0.507
U.K.	0.670	0.878	0.847
U.S.	0.364	0.548	0.477

All the results here are not different from the results we have got before. All major conclusions hold here.

In conclusion, though several situations do not have solvable solutions due to R program, the results we have gotten here is not too different from the results we have gotten before. Thereby, the results pass the robust test.