VOLATILITY TRANSMISSION BETWEEN U.S. SECTOR ETFs: AN APPLICATION OF DIEBOLD-YILMAZ CONNECTEDNESS FRAMEWORK

Van Hau Nguyen

A thesis submitted to
Auckland University of Technology
in partial fulfilment of the requirements for the degree of
Master of Business (MBus)

Faculty of Business and Law
1 September, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

ACKNOWLEDGEMENT

I am very thankful to Dr. José Da Fonseca at Auckland University of Technology (AUT) for useful suggestions and valuable comments from the beginning to the completion of this thesis. Besides, the support of the Finance Department at AUT is also acknowledged.

ABSTRACT

This paper utilizes the Connectedness framework of Diebold and Yilmaz (2011) to investigate volatility transmission between ten iShares sector ETFs over the sample ranging from 2 January 2001 to 31 December 2014. Generally, the empirical results indicate that the total volatility spillover of ten examined sector ETFs is time-varying and sensitive to market as well as economic events. Over time, Energy and Basic Materials are the two largest net volatility transmitters while Consumer Services, Healthcare, and Consumer Goods are the top three largest net volatility receivers among the sectors. Findings imply that oil prices have an impact on volatility of other sectors as well as the market index as a whole. Findings are useful for not only the investors in evaluating the overall risk of their portfolios but also the policy makers in addressing financial stability issues and problems related to contagion between sectors. Furthermore, this paper contributes to the literature by providing the first analysis of volatility transmission between sectors using ETF assets.

I. INTRODUCTION

Nowadays, investing in sector ETFs has become tremendously popular. However, the investors do not pay much attention to volatility transmission between sectors which makes up the overall risk of their portfolios. By definition, volatility transmission or volatility spillover is an issue that volatility shock of an asset propagates to another asset. In terms of volatility, Diebold and Yilmaz (2011) say that volatility tracks the fear of investors and is particularly crisis-sensitive. According to Ross (1989), return volatility of an asset is sensitive to the rate of information flow. Also, volatility patterns between markets (sectors) are distinct due to differences in the rate of information flow and the time spent to decode that information. So far Diebold-Yilmaz Connectedness framework has not been applied to analyze volatility transmission between sectors. Overall, there are two dimensions in this paper. First, volatility transmission between sectors is analyzed in a sense which is static (unconditional). Second, the sample is rolled to understand the dynamic (time-varying) evolution of volatility transmission.

Generally, this paper uses high frequency data and the Connectedness framework of Diebold and Yilmaz (2011) to examine volatility transmission between ten iShares sector ETFs over the sample ranging from 2 January 2001 to 31 December 2014. Overall, the empirical results indicate that the total volatility spillover of ten examined sector ETFs is time-varying and sensitive to market as well as economic events. Moreover, the ten sectors have become more connected since late 2006. Over the examined sample, Energy and Basic Materials are the two largest net volatility transmitters while Consumer Services, Healthcare, and Consumer Goods are the top three largest net volatility receivers among the sectors. During the highly turbulent period of 2001 which corresponds to the burst of internet bubble, Technology and Telecommunications account the most for volatility of other sectors. Whereas, Financials is largely responsible for volatility of other sectors during the 2007 – 2009 global financial crisis (GFC). Findings from the paper suggest two implications. First, news and shocks that impact a certain sector will ultimately spread over other sectors through the high connectedness. Second, findings also imply the impact of oil prices on the market index which is the aggregation of all the sectors.

This paper has both practical and academic contributions. In terms of practical contributions, this paper provides empirical findings which are useful for the investors who are interested in the sector investing or have exposure on stocks in different sectors simultaneously. Moreover, the determination of cycles, bursts, and trends in volatility transmission between sectors over time assists the policy makers in addressing financial stability issues and problems related to contagion between sectors. Regarding academic contributions, this paper applies Diebold-Yilmaz Connectedness framework in the volatility spillover measurement at sectoral level for the first time, providing reference for further studies. Besides, this paper contributes to the literature by completing existing studies devoted to volatility transmission at sector level.

This paper is structured as follows. First, section II provides a literature review. Second, section III shows the data and methodology. Third, the empirical results are presented in section III. Furthermore, section IV briefly concludes. Lastly, the references are included in section V while figures and tables are gathered in section VI.

II. LITERATURE REVIEW

Let's first review the development and the application of Diebold-Yilmaz Connectedness framework through a series of papers ranging from 2009 to 2014. Initially, Diebold and Yilmaz (2009a) use the methodology called Spillover Index to estimate volatility spillovers between nineteen global equity markets from January 1992 to November 2007. The methodology follows directly the familiar notion of a variance decomposition associated with an N-variable vector autoregression. Next, Diebold and Yilmaz (2009b) apply that methodology to examine the return and volatility spillovers between five equity markets in the Americas from January 1992 to October 2008. Note that both papers use weekly high, low, opening, and closing prices obtained from underlying daily high/low/open/close data to estimate weekly stock return volatility. Diebold and Yilmaz (2010) apply the Spillover Index methodology to investigate volatility spillovers between four U.S. asset markets (namely stock, bond, commodity, and exchange rate markets) from January 1999 to January 2010. More precisely, the paper estimates the daily variance using daily high and low prices. The paper shows that cross-market volatility spillovers are quite limited until the GFC. Afterwards, Diebold and Yilmaz (2011) study the connectedness between thirteen U.S. financial institutions from May 1999 to April 2010. The connectedness concept, that quantifies to which extent two variables are related, is equivalent to volatility spillover concept and turns out to be a convenient theoretical framework to analyze contagion risk that becomes prevalent during the GFC. Contrarily to the previous papers, Diebold and Yilmaz (2011) use 5-Min Intraday data to estimate the realized volatility. In this paper, the authors show that the Connectedness framework relates to the modern network theory and modern measures of systematic risks. For instance, the total connectedness is equivalent to the mean degree of a weighted and directed network. Besides, the total directional connectedness from other assets suggests the exposures of individual firms to systematic shocks from the network while the total directional connectedness to other assets indicates the contribution of individual firms to systematic network events. Furthermore, the Connectedness framework is employed to study the volatility connectedness of banks on both sides of the Atlantic (see (Diebold & Yilmaz, 2013a)), the dynamics of global business cycle connectedness (see (Diebold & Yilmaz, 2013b)), and the Trans-Atlantic volatility connectedness between financial institutions (see (Diebold & Yilmaz, 2014)). Overall, Diebold-Yilmaz framework is applicable for the spillover measurement in returns and returns volatilities between individual assets, asset portfolios, or assets markets, etc., both within and across countries, revealing spillover trends, cycles, bursts, etc. As suggested by the authors, the framework nonetheless avoids the contentious issues regarding the definition and existence of episodes of "contagion" or "herd behavior". However, the framework has a feature of numerical simplicity and is capable to handle a large number of assets. Hence, it has attracted a strong interest among academics and is applied in many recent empirical studies (for an example, see (Zhou, Zhang, & Zhang, 2012)).

Besides Diebold-Yilmaz framework, it is necessary to review different types of models which are capable to measure volatility transmission. The concept of Conditional Heteroscedasticity introduced by Engle (1982) and the extension to Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models proposed by Bollerslev (1986) have been employed widely in many studies to analyze the relations between financial markets. Hamao, Masulis, and Ng (1990) are the pioneers in using the univariate GARCH to investigate the relations across international markets. Regarding the shortcoming of the univariate estimation, the framework is unable to explore the complicated between volatilities in two directions as well as to exploit the covariance between two series. The multivariate framework is developed and attracts a lot of interest among researchers. Note that the first bivariate GARCH model is proposed by Engle and

Kroner (1995). Nowadays, many types of GARCH models have been created, and the number of members in GARCH family keeps increasing. Besides GARCH, the Markov regime switching models have been utilized extensively for the measurement of volatility transmission between financial markets. Although the models are initially for the mean equation, they can also be applied in volatility modelling (see (Pelletier, 2005)). Moreover, Stochastic Volatility models are also useful to examine volatility transmission between financial markets. Taylor (1982) provides the most basic Stochastic Volatility models, and Taylor (1994) presents a detailed revision on Stochastic Volatility models. Diebold-Yilmaz framework is preferred in this paper because it is simple to implement as it avoids complicated numerical methods.

It is important to highlight the fact that studies on volatility transmission between U.S. sectors are very limited. Relevant articles include Ewing (2002), Hassan and Malik (2007), Balli, Balli, and Louis (2013), and Barunik, Kocenda, and Vacha (2015). Ewing (2002) examines the interrelationship between five major sectors of the S&P stock indexes (i.e., Capital Goods, Financials, Industrials, Transportation, and Utilities). This paper uses monthly data ranging from January 1988 to July 1997 and the generalized forecast error variance decomposition technique within a vector auto-regression VAR framework. Findings show that unexpected news or shocks in one sector impact returns of the other sectors significantly. Hassan and Malik (2007) use daily data and the multivariate GARCH to measure the transmission of volatility and shocks between several U.S. major sectors (i.e., Financials, Industrials, Consumer Discretionary, Consumer Staples, Healthcare, Energy, and Technology) over the sample ranging from 1 January 1992 to 6 June 2005. They find the significant interaction between second moments of the U.S. equity sector indexes. Balli et al. (2013) examine the integration of the Euro- and US-wide sector equity indices using weekly data of 17 sector equity indices from 1992 to 2009. The authors divide the selected equity indices into four groups such as Production and Industry, Consumer Goods and Services, Financials, and TMT (which represents Technology, Media, and Telecommunications). Regarding the volatility spillover analysis, the Production and Industry, Consumer Goods and Services, and TMT react similarly to local shocks. More precisely, Financials is the most sensitive sector among all the sectors. These results are irrespective of the model used or whether the U.S. or the Euro area is considered. Barunik et al. (2015) study the connectedness asymmetry of the 21 most liquid U.S. stocks from the seven main market sectors (i.e., Financials, Information Technology, Energy, Consumer Discretionary, Consumer Staples, Healthcare, and Telecommunications) from August 2004 to December 2011. The paper utilizes Diebold-Yilmaz Connectedness methodology and uses 5-Min Intraday data to calculate realized variances and semi-variances. The authors conclude that both bad and good volatilities are transmitted at different magnitudes in all sectors. More precisely, the asymmetries in spillovers found in Consumer Discretionary, Consumer Staples, Telecommunications, and Healthcare are larger than those observed in Financials, Information Technology, and Energy.

At the industry level, Lee, Elkassabgi, and Hsieh (2014) study the causality relationship between the utilities industry and the nine other S&P 500 industries using the methodology developed by Hacker and Hatemi-J (2006). Data includes 416 S&P 500 listed firms and spans from 23 November 2011 to 31 January 2012. Findings indicate the causality of volatility of the utilities industry on volatility of all other industries except information technology and telecommunication services industries. In the reverse direction, only financial industry has an impact on the utilities industry.

Finally, since oil prices represent the energy sector, several studies regarding volatility transmission between oil prices and U.S. sector returns are considered relevant. Malik and Ewing (2009) analyze the transmission of volatility and shocks between oil prices and five major market sectors (namely, Financials, Industrials, Consumer Services, Healthcare, and Technology). The paper employs the bivariate GARCH and uses weekly data ranging from 1 January 1992 to 30 April 2008. Findings show the existence of spillover effects. In terms of the Oil - Financials pair, news from Financials has an indirect impact on oil return volatility. However, oil return volatility has neither a direct nor an indirect impact on Financials. Regarding the Oil - Technology pair, shocks and volatility of oil returns contribute indirectly to return volatility of Technology. Nevertheless, the impact in the reverse direction is insignificant. Regarding the Oil - Consumer Services pair, oil return volatility is both directly and indirectly impacted by return volatility of Consumer Services. Moreover, volatility of oil returns does affect the return volatility of Consumer Services. Referring to the Oil - Healthcare pair, Healthcare's return volatility can be directly and indirectly explained by volatility of oil returns. Also, oil return volatility is indirectly affected by volatility of Healthcare. Regarding the Oil - Industrials pair, return volatility of Industrials turns out to have a direct impact on oil return volatility. However, no impact of oil return volatility on return volatility of Industrials is detected. Arouri, Jouini, and Nguyen (2011) use the VAR-GARCH model to explore volatility transmission between oil prices and stock markets in Europe and the United States from a sector perspective. Examined sectors include Automobiles & Parts, Financials, Industrials, Basic Materials, Technology, Telecommunications, and Utilities. The paper uses weekly data from S&P sector indexes, and the sample ranges from 1 January 1998 to 31 December 2009. Findings show that the spillover is usually unidirectional from oil markets to stock markets in Europe but bidirectional in the United States. Lelis and Pirhadi (2011) examine the transmission of shocks and volatility between oil prices and the nine major industries in Europe and the U.S (such as Basic Materials, Consumer Goods, Consumer Services, Financials, Healthcare, Industrials, Technology, Telecommunications, and Utilities). The paper uses weekly data ranging from 1 January 1999 to 15 April 2011. Regarding the U.S. industries, the paper concludes that oil news has significantly positive impacts on Basic Materials, Industrials, and Utilities but a significantly negative impact on Consumer Services. Also, the coefficients are highly sensitive to the estimation sample. Lee, Jang, and Huang (2012) investigate oil price changes and stock prices in the G-7 countries. The paper uses monthly data ranging from January 1991 to May 2009 and employs the unrestricted VAR model. In terms of findings related to the U.S., oil prices shocks have significant impacts on Information Technology and Consumer Staples.

All but Barunik et al. (2015) papers use sophisticated methodologies, turning the estimation results possibly unreliable. The numerical simplicity of Diebold-Yilmaz framework is one of its most interesting properties as this study will show.

III. DATA & METHODOLOGY

1. DATA

Today, the standard way to analyze volatility is to use high frequency data as shown in studies of Andersen, Bollerslev, Diebold, and Ebens (2001) and Andersen, Bollerslev, Diebold, and Labys (2003). Hence, this paper uses 5-Min Intraday data from Thomson Reuters database to estimate realized volatility. This paper examines data during trading hours from 9:45 am to 16:00 pm ET. Though the core trading session begins at 9:30 am, data for the first 15 minutes is excluded to avoid opening hour effects. Although the data is supposed to be sampled at 5-Min, sometimes the distance between two quotes is more than 5 minutes. In this case, it is assumed as 5-Min data because the impact will be marginal. Moreover, as the data does not give the same number of days for all ETFs, the solution is to keep only the days for which all the ETFs are available. The sample spans from 2 January 2001 to 31 December 2014. This sample includes several transition periods. The data comprises ten iShares' sector ETFs which are traded on NYSE Arca Exchange and have the inception date of 12 June 2000. The detailed information of the examined ETFs is shown in Table 1.1 and Table 1.2.

[Insert Table 1.1 and Table 1.2 around here]

While the static analysis examines volatility transmission between sectors using the full sample, the dynamic analysis investigates the time-varying evolution of volatility transmission between sectors using rolling samples. For the dynamic analysis, this paper also uses data for oil price, short-term interest rate, long-term interest rate, inflation rate, unemployment rate, and house price. All the data is retrieved from the Federal Reserve Bank of St. Louis. Note that the crude oil price is the spot price of West Texas Intermediate crude oil. The short-term rate is the Effective Federal Funds rate while the long-term interest rate is the 10-Year Treasury Constant Maturity rate. The house price is the median sales price of existing homes. Besides, the inflation rate is on an annual basis while the remaining data is on a monthly basis.

2. METHODOLOGY

2.1. Realized Variances

For a given ETF on a given day, the realized variance is computed by taking the sum of square log price changes over 5-Min intervals on that day. Let t_1, t_2, …, t_n denote the observed dates, and $t_{1,1}$, $t_{1,2}$, …, $t_{1,n}$ denote the sub-divisions of day t_1. Also assume $P_{t_{1,m}}$ as the $m^{rd/nd/th}$ relevant 5-Min Intraday price of day t_1. The realized variance of day t_1 is calculated as

$$RV_{t_1} = \sum_{m=1}^{n-1} \left[ln\left(\frac{P_{t_{1,m+1}}}{P_{t_{1,m}}}\right)\right]^2.$$

See Andersen et al. (2001) and Andersen et al. (2003) for more information about realized variances. Totally, there are 3,498 days, and each day comprises 10 realized variances of ten sector ETFs. For each day, if there is an outlier observation for a (or more) sector, realized variances of all ETFs on that day are set to equal the realized variances on the previous day. As a result, the realized variances are revised before being put into Diebold-Yilmaz Connectedness model.

2.2. Generalized Vector Autoregressions

This paper utilizes the methodology of Diebold and Yilmaz (2011). The methodology is intimately related to the familiar econometric notion of a variance decomposition in which the forecast error variance of variable i is decomposed into parts attributed to the various variables in the system. Diebold and Yilmaz (2011) denote the ij-th H-step variance decomposition component by d_{ij}^H; that is, the fraction of variable i's H-step forecast error variance due to shocks in variable j. All of the spillover measures – from simple pairwise to system-wide – are based on the "non-own," or "cross," variance decompositions, $d_{ij}^H, i, j = 1, \dots, N, i \neq j$. The key is that $i \neq j$.

Consider an N-dimensional covariance-stationary data-generating process (DGP) with orthogonal shocks: $x_t = \ominus(L)u_t,\ \ominus(L) = \ominus_0 + \ominus_1 L + \ominus_2 L^2 + \cdots, E(u_t u_t') = I$. Note that $\ominus_0$ does not need to be diagonal. All aspects of spillover are contained in this very general representation. In particular, contemporaneous aspects of spillover are summarized in $\ominus_0$, and dynamic aspects in $\{\ominus_1,\ \ominus_2, \dots\}$. Nevertheless, attempting to understand spillover via the potentially many hundreds of coefficients in $\{\ominus_0, \ominus_1,\ \ominus_2, \dots\}$ is typically fruitless. One needs a transformation of $\{\ominus_0,\ \ominus_1,\ \ominus_2, \dots\}$ that better reveals and more compactly summarizes spillover. Variance decompositions achieve this.

Spillover Table Schematic

	x_1	x_2	$\cdots$	x_N	FROM
x_1	d_{11}^H	d_{12}^H	$\cdots$	d_{1N}^H	$\sum_{j=1}^N d_{1j}^H$, j ≠ 1
x_2	d_{21}^H	d_{22}^H	$\cdots$	d_{2N}^H	$\sum_{j=1}^N d_{2j}^H$, j ≠ 2
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
x_N	d_{N1}^H	d_{N2}^H	$\cdots$	d_{NN}^H	$\sum_{j=1}^N d_{Nj}^H$, j ≠ N
TO	$\sum_{i=1}^N d_{i1}^H$, i ≠ 1	$\sum_{i=1}^N d_{i2}^H$, i ≠ 2	$\cdots$	$\sum_{i=1}^N d_{iN}^H$, i ≠ N	$\frac{1}{N}\sum_{i,j=1}^N d_{ij}^H$, i ≠ j

The table above is called the spillover table which proves central for understanding the various spillover measures and their relationships. Its main upper-left $N \times N$ block contains the variance decompositions. For future reference Diebold and Yilmaz (2011) call that upper-left block a “variance decomposition matrix,” and they denote it by $D^H = [d_{ij}^H]$. The spillover table simply augments D^H with a rightmost column containing row sums, a bottom row containing column sums, and a bottom-right element containing the grand average, in all cases for $i \neq j$. The off-diagonal entries of D^H are the parts of the N forecast-error variance decompositions of relevance from a spillover perspective; in particular, they measure pairwise directional volatility spillover. Since $S_{i \leftarrow j}^H \neq S_{j \leftarrow i}^H$, there are $N^2 - N$ separate pairwise directional volatility spillover measures. The pairwise directional volatility spillover from j to i is defined as

$$S^H_{i \leftarrow j} = d^H_{ij}.$$

There are $\frac{N^2-N}{2}$ net (as apposed to gross) pairwise directional volatility spillover measures. The net pairwise directional volatility spillover is defined as

$$S^H_{ij} = S^H_{j \leftarrow i} - S^H_{i \leftarrow j}.$$

Diebold and Yilmaz (2011) call the off-diagonal row and column sums, labeled "from" and "to" in the spillover table, the total directional volatility spillover measures. There are $2N$ total directional volatility spillover measures, N to-spillover measures or transmitted spillover measures, and N from-spillover measures or received spillover measures. Diebold and Yilmaz (2011) define the total directional volatility spillover from other sectors to i as

$$S^H_{i \leftarrow *} = \sum_{\substack{j=1 \\ j \neq i}}^{N} d^H_{ij},$$

and the total directional volatility spillover to other sectors from j as

$$S^H_{* \leftarrow j} = \sum_{\substack{i=1 \\ i \neq j}}^{N} d^H_{ij}.$$

Regarding net total effects, there are N net total directional volatility spillover measures. The net total directional volatility spillover is defined as

$$S^H_{i} = S^H_{* \leftarrow i} - S^H_{i \leftarrow *}.$$

Finally, the grand total of the off-diagonal entries in D^H (equivalently, the sum of the "from" column or "to" row) measures the total volatility spillover. There is just one total volatility spillover measure, and it is defined as

$$S^H = \frac{1}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} d^H_{ij}.$$

Diebold and Yilmaz (2011) find that the total volatility spillover is robust to Cholesky ordering; that is, the range of the total volatility spillover estimates across orderings is often quite small. However, directional volatility spillover is sometimes more sensitive to Cholesky ordering. Like Cholesky-factor variance decompositions, generalized variance decompositions (GVDs) rely on a largely data-based identification scheme, but they are independent of ordering. GVDs were introduced in Pesaran and Shin (1998), which builds on Koop, Pesaran, and Potter (1996). The H-step generalized variance decomposition matrix $D^{gH} = \left[d_{ij}^{gH}\right]$ has entries

$$d_{ij}^{gH} = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' \Theta_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' \Theta_h \Sigma \Theta_h' e_i\right)},$$

where e_j is a selection vector with j^{th} element unity and zeros elsewhere, Θ_h is the coefficient matrix multiplying the h-lagged shock vector in the infinite moving-average representation of the non-orthogonalized VAR, Σ is the covariance matrix of the shock vector in the non-orthogonalized VAR, and σ_{ij} is the j^{th} diagonal element of Σ. Because shocks are not necessarily orthogonal in the GVD environment, sums of forecast error variance contributions are not necessarily unity (that is, row sums of D^g are not necessarily unity). Hence, the generalized spillover indexes are based not on D^g, but rather on $\widetilde{D}^g = \left[\tilde{d}_{ij}^g\right]$, where $\tilde{d}_{ij}^g = \frac{d_{ij}^g}{\sum_{j=1}^N d_{ij}^g}$. By construction $\sum_{j=1}^N \tilde{d}_{ij}^g = 1$ and $\sum_{i,j=1}^N \tilde{d}_{ij}^g = N$. Using $\widetilde{D}^g$ generalized spillover measures $\tilde{S}, \tilde{S}_{*\leftarrow j}, \tilde{S}_{i\leftarrow *}, \tilde{S}_i, \tilde{S}_{i\leftarrow j}, \tilde{S}_{j\leftarrow i}$, and $\tilde{S}_{ij}$ can be immediately calculated.

Throughout this paper (except section 3.1.2), the Generalized VAR model is estimated using 3 lags and a 12-day forecast horizon. The window width for the static analysis is 3,498 days while it is 100 days for the dynamic analysis.

IV. EMPIRICAL RESULTS

This section includes three important sub-sections. First, section 1 presents several preliminary tests. Second, section 2 shows the static analysis. Lastly, the paper's central focus is section 3 which provides the dynamic analysis.

1. PRELIMINARY TESTS

[Insert Figure 1 around here]

Before discussing the preliminary tests on volatility for ten sector ETFs, it is interesting to make some descriptions of volatility plots in Figure 1. Obviously, there are two episodes during which the realized variances of all sectors increase substantially. The first episode lasts from 2001 to late 2003. This episode coincides with the 2001 Recession in U.S., the 9/11 terrorist attacks in 2001, and the burst of internet bubble in early 2000s. During the first episode, the volatility plots of IYW and IYZ experience wider surges than those of other sectors. The second episode spans from mid 2007 to the end of 2009. This episode coincides with the subprime mortgage crisis in 2007 and the GFC. During the second episode, the volatility plot of IYF experiences wider surge than that of any other sectors.

1.1. Descriptive Statistics

[Insert Table 2 around here]

Table 2 presents descriptive statistics for daily realized variances of ten sector ETFs over the sample ranging from 2 January 2001 to 31 December 2014.

In terms of the central tendency, IYW has the highest mean of 2.63E-04 while IYK has the lowest mean of 8.99E-05. Referring to the measures of dispersion, IYZ has the highest Std.Dev of 4.42E-04 while IYK has the lowest Std.Dev of 1.40E-04. It is important to consider whether there is any bias in the dispersion of the data indicated by the skewness. Obviously, all the series are positively skewed. IYE ($Sk_{IYE} = 7.27$) and IYZ ($Sk_{IYZ} = 3.42$) have the most and the least positively skewed series. By definition, positive skewness is resulted from the distribution with a long tail to the right. While skewness signals the degree of symmetry in the frequency distribution, kurtosis indicates the peakedness of that distribution. Positive excess kurtosises observed in all series suggest the leptokurtic distributions which are more peaked than the normal distribution. IDU ($K_{IDU} = 85.11$) and IYZ ($K_{IYZ} = 18.51$) have the most and the least fat-tailed distributions, suggesting the higher probability of attaining an extreme realized variance outcome than a normal realized variance outcome.

1.2. Stationary Tests

[Insert Tables 3.1, 3.2, 3.3 around here]

Tables 3.1, 3.2, and 3.3 in turn display the outcomes of Augmented Dickey-Fuller tests for stationarity (see (Dickey & Fuller, 1981)). These tests are crucial since non-stationary series may result in spurious regression.

Regarding 95% confidence interval, in all three tables, the ten series are stationary at level as the test statistics in absolute terms are all higher than the absolute 5% test critical value. Moreover, p-values below 0.05 also suggest the rejection of null hypotheses, signaling that no unit root exists.

In summary, it is statistically significant to conclude that each of the ten series is a stationary process, and thereby not having a stochastic or deterministic trend.

1.3. Pairwise Granger Causality Tests

[Insert Table 4 around here]

Note that the Connectedness framework is applied under the assumption that all sectors are connected. Fortunately, the Pairwise Granger Causality tests proposed by Granger (1969) allow the examination of short-term causal effects in each sector pair. Totally, there are 90 sector pairs, and each of which is tested three times using varying lags from 1 to 3. Outcomes for all the tests are summarized in Table 4.

Regarding 95% confidence interval, there are 9 out of 270 tests having statistically insignificant p-values (which are equal or higher than 0.05). In each of these tests, the null hypothesis of no Granger Causality is accepted. However, there is no sector pair that has the null hypotheses accepted at all the examined lags. For instance, IYZ Granger causes IYE at 1 lag and 2 lags. Also, IYK Granger causes IYF at 2 lags and 3 lags. Moreover, Granger causality from IYW to IYF is found at 1 lag. Additionally, the short-term causal effect from IYF to IYW occurs at 1 lag and 3 lags. Regarding the tests for Granger causality from IYZ to IYF, p-values are statistical significant at 1 lag and 2 lags. Furthermore, the test for Granger causality from IYW to IYM at 1 lag experiences a statistically significant p-value. Lastly, the short-term causal effect from IYZ to IYM exists at 1 lag and 2 lags.

In summary, the short-term causal effects are found in all sector pairs for some specific lags.

2. STATIC (FULL SAMPLE, UNCONDITIONAL) ANALYSIS

[Insert Table 5.1 around here]

Table 5.1 is the full sample volatility spillover table of ten sector ETFs over the sample ranging from 2 January 2001 to 31 December 2014. The table is informative about how the spillover measures are averaged over the full sample.

Let's first start with the pairwise directional volatility spillover measures ($\tilde{S}^{H}_{i\leftarrow j}$) which are the off-diagonal elements of the 10x10 matrix. The high pairwise directional volatility spillover measures between the two sectors imply the strong ties between them. The first highest pairwise directional volatility spillover of 20.5% is observed from IYE to IYM ($\tilde{S}^{12}_{IYM\leftarrow IYE}$). In return, the pairwise directional volatility spillover from IYM to IYE ($\tilde{S}^{12}_{IYE\leftarrow IYM}$) is 19.5%. As a result, the net pairwise directional volatility spillover from IYE to IYM ($\tilde{S}^{12}_{IYE,IYM}$) is 1%. The little difference between these two pairwise directional volatility spillovers indicates that the two sectors affect each other almost equally. The next largest pairwise directional volatility spillover of 19.1% takes place from IYF to IYJ ($\tilde{S}^{12}_{IYJ\leftarrow IYF}$). In the reverse direction, the pairwise directional volatility spillover from IYJ to IYF ($\tilde{S}^{12}_{IYF\leftarrow IDJ}$) is a lower 6.9%. The net pairwise directional volatility spillover between these two sectors ($\tilde{S}^{12}_{IYF,IYJ}$) is 12.3%. Furthermore, IYM and IYJ also have high pairwise directional volatility spillover measures. The pairwise directional volatility spillovers from IYM to IYJ ($\tilde{S}^{12}_{IYJ\leftarrow IYM}$) and from IYJ to IYM ($\tilde{S}^{12}_{IYM\leftarrow IYJ}$) are 17.8% and 7.3%, respectively. Netting out these two values gives the net pairwise directional volatility spillover ($\tilde{S}^{12}_{IYM,IYJ}$) of 10.4%.

Second, consider the total directional volatility spillover from the others to each of the ten sectors ($\tilde{S}^{H}_{i\leftarrow *}$), which is the row sum of the pairwise directional volatility spillover measures. In other words, the "FROM" column measures the shares of the volatility shocks received from other sector stocks in the total variance of the forecast error for each stock. By definition, it is equal to 100% minus the own share of the total forecast error variance (Diebold & Yilmaz, 2011). As the own-effects (diagonal elements of the matrix) range between 15.7% and 47.4%, the total directional volatility spillovers in the "FROM" column range between 52.5% and 95.8%. Over the full sample, IYK $\left(\tilde{S}^{12}_{IYK\leftarrow *} = 95.8\%\right)$, IYH $(\tilde{S}^{12}_{IYH\leftarrow *} = 93.6\%)$, and IYC $(\tilde{S}^{12}_{IYC\leftarrow *} = 92.2\%)$ are sectors which receive the highest percentages of shocks from the others. Whereas, IYW $(\tilde{S}^{12}_{IYW\leftarrow *} = 52.6\%)$, IYZ $(\tilde{S}^{12}_{IYZ\leftarrow *} = 55.5\%)$, and IYF $(\tilde{S}^{12}_{IYF\leftarrow *} = 63\%)$ are sectors which receive the lowest percentages of shocks from the others.

Third, consider the total directional volatility spillover from each of the ten sectors to the others $(\tilde{S}^{H}_{*\leftarrow i})$, which is the column sum of all pairwise directional volatility spillover measures. As each sector's contribution to the forecast error variances of the other sectors is not constrained to add up to 100%, entries in the "TO" row can exceed 100% (Diebold & Yilmaz, 2011). Apparently, IYE $\left(\tilde{S}^{12}_{*\leftarrow IYE} = 135\%\right)$ contributes the most to the forecast error variances of other sectors by having the highest degree of total transmitted spillover. IYM $\left(\tilde{S}^{12}_{*\leftarrow IYM} = 130\%\right)$, IYF $\left(\tilde{S}^{12}_{*\leftarrow IYF} = 126.1\%\right)$, and IYZ $\left(\tilde{S}^{12}_{*\leftarrow IYZ} = 111.1\%\right)$ rank second, third, and fourth, respectively.

Furthermore, consider the net total directional volatility spillover $(\tilde{S}^{H}_{i})$, which is the difference between the total transmitted spillover and the total received spillover. Sectors having positive net total directional volatility spillover in the descending order are IYE $\left(\tilde{S}^{12}_{IYE} = 64.7\%\right)$, IYF $\left(\tilde{S}^{12}_{IYF} = 63.1\%\right)$, IYM $\left(\tilde{S}^{12}_{IYM} = 56\%\right)$, IYZ $\left(\tilde{S}^{12}_{IYZ} = 55.7\%\right)$, and IYW $\left(\tilde{S}^{12}_{IYW} = 25.5\%\right)$. These sectors are considered net transmitters of volatility shocks. In other words, these sectors, on average, transmit more volatility shocks to the others than receive volatility shocks from the others. On the contrary, the remaining sectors are the net receivers of volatility shocks over the full sample due to their negative net total directional volatility spillovers. In details, they are IDU $\left(\tilde{S}^{12}_{IDU} = -31.1\%\right)$, IYJ $\left(\tilde{S}^{12}_{IYJ} = -31.8\%\right)$, IYC $\left(\tilde{S}^{12}_{IYC} = -51.1\%\right)$, IYH $\left(\tilde{S}^{12}_{IYH} = -72.2\%\right)$, and IYK $\left(\tilde{S}^{12}_{IYK} = -78.7\%\right)$.

Finally, consider the total volatility spillover ($\tilde{S}^{H}$), which is approximately the grand off-diagonal column/row sum relative to the grand column/row sum including diagonals. The total volatility spillover appearing in the lower right corner of Table 4A indicates that on average, across the entire sample, 77.1% of the volatility forecast error variance in ten sector ETFs comes from spillovers.

In summary, the pairwise directional volatility spillovers, the total directional volatility spillovers, and the total volatility spillover between the ten sector ETFs over the sample ranging from 2001 to 2014 are quite high.

3. DYNAMIC ANALYSIS

As the main window width is 100 days, there are 3,399 rolling samples. The dynamic analysis includes four sub-sections. First, section 3.1 analyzes the rolling total volatility spillover. Second, section 3.2 discusses the rolling total directional volatility spillover. Third, section 3.3 provides the rolling net total volatility spillover. Lastly, section 3.4 shows the rolling net pairwise directional volatility spillover during the 2001 Recession and the GFC.

3.1 Rolling Total Volatility Spillover

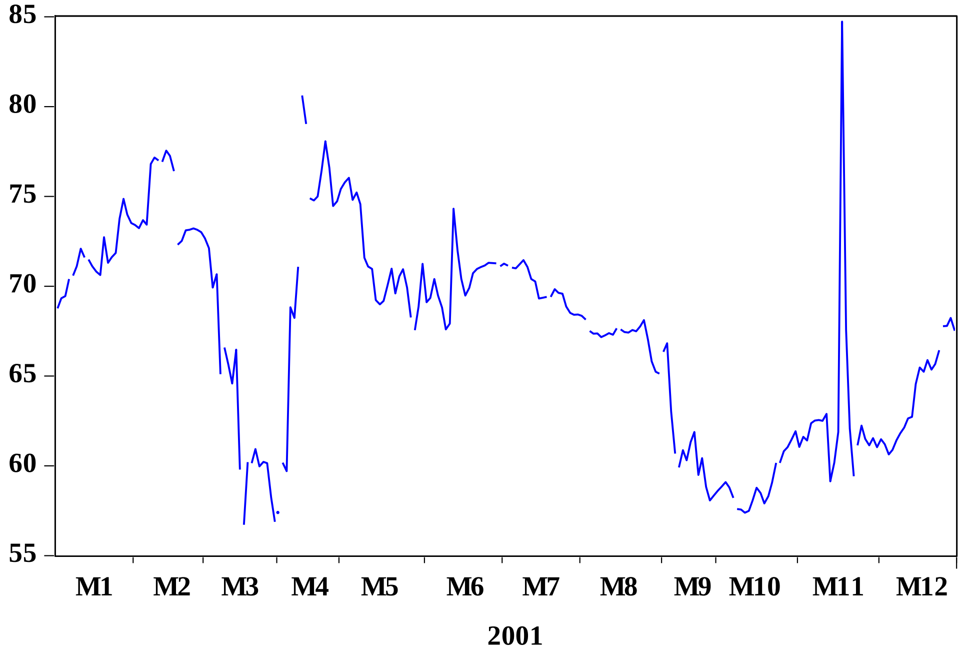
3.1.1. Main Test

[Insert Figure 2.2 around here]

The plot in Figure 2.2 shows the total volatility spillover over 100-day rolling-sample windows. Generally, the lowest total volatility spillover observed is 49.2% while the highest one is 90.1%. Moreover, the average total volatility spillover is a high 76.4% which is quite close to the unconditional value of 77.1% observed in the static analysis. Apparently, the total volatility spillover of the ten sectors is high over time. Even in the least volatile window, the total volatility spillover is roughly 50%. In other words, the examined sectors are highly connected. The fact that the total volatility spillover fluctuates a lot justifies the dynamic analysis, showing an evidence of time variation. Based on the width of the range within which the total volatility spillover fluctuates, the plot in Figure 1 is divided into four main periods: 2001 - 2002, 2003 - 2004, 2005, and 2006 - 2014. It is interesting to discuss each period together with the events that occur during these periods.

3.1.1.1. The 2001 – 2002 Period

Over the first period from 2001 to 2002, the total volatility spillover fluctuates between 55% and 80%. This period coincides with the burst of internet bubble in early 2000s.

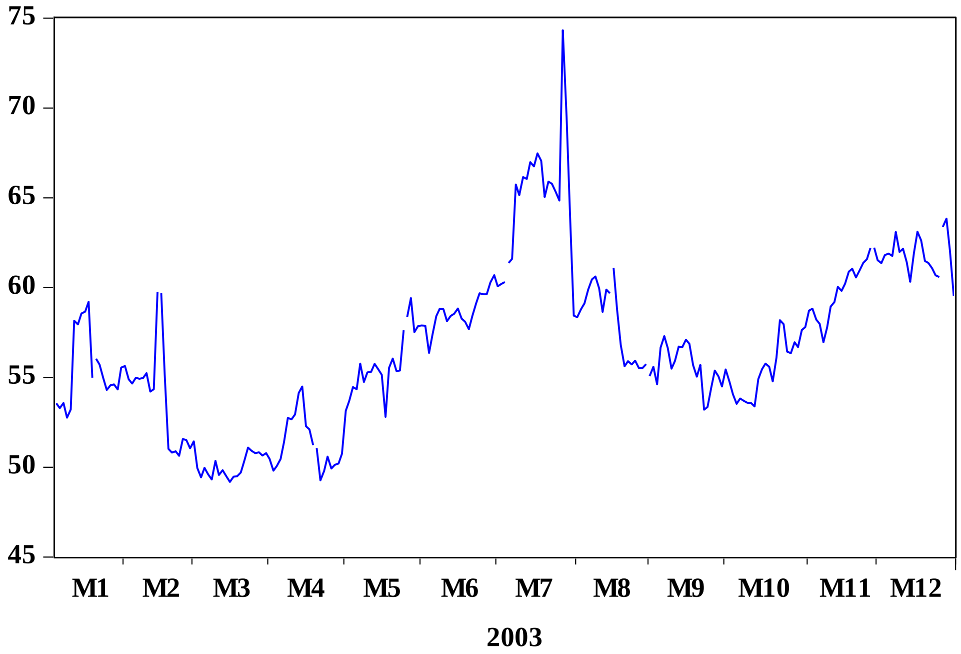


In 2001, notable events that impact the total volatility spillover are the 2001 Recession lasting from March to November and the 9/11 terrorist attacks. Note that the total volatility spillover begins at about 70% in the first estimation window because the year 2000 ends in the context of economic slowdown. In early 2001, disappointing earnings statements and profit warnings make the investors concern about the deteriorating economic condition. During the 1st quarter, the phrase "sell-off" dominates the market. Note that Technology struggles the most. In response, the total volatility spillover increases to above 75% in mid 1st quarter and decreases to under 60% in late 1st quarter. The drop in the total volatility spillover can be explained by the rebound of stocks in Technology. However, the total volatility spillover surges back to above 75% in early 2nd quarter. It then swings around 70% though mid 3rd quarter. The drop in share prices of companies in Technology and Telecommunications around mid 3rd quarter influences the total volatility spillover movement. After the market halt caused by the 9/11 terrorist attacks, the total volatility spillover stays around 65% on the first days of resume. According to Straetmans, Verschoor, and Wolff (2008), the 9/11 terrorist attacks significantly increase both the downside risk and co-movements of the U.S. sector indexes with the market. Afterwards, the total volatility spillover falls under 60% in late 3rd quarter. It is the decline in oil prices which boosts the total volatility spillover in mid November. In fact, oil prices drop to the lowest level of the year, \$17/b, around mid November. The 4th quarter sees the total volatility spillover move around 60% before ending 2001 at above 65%.

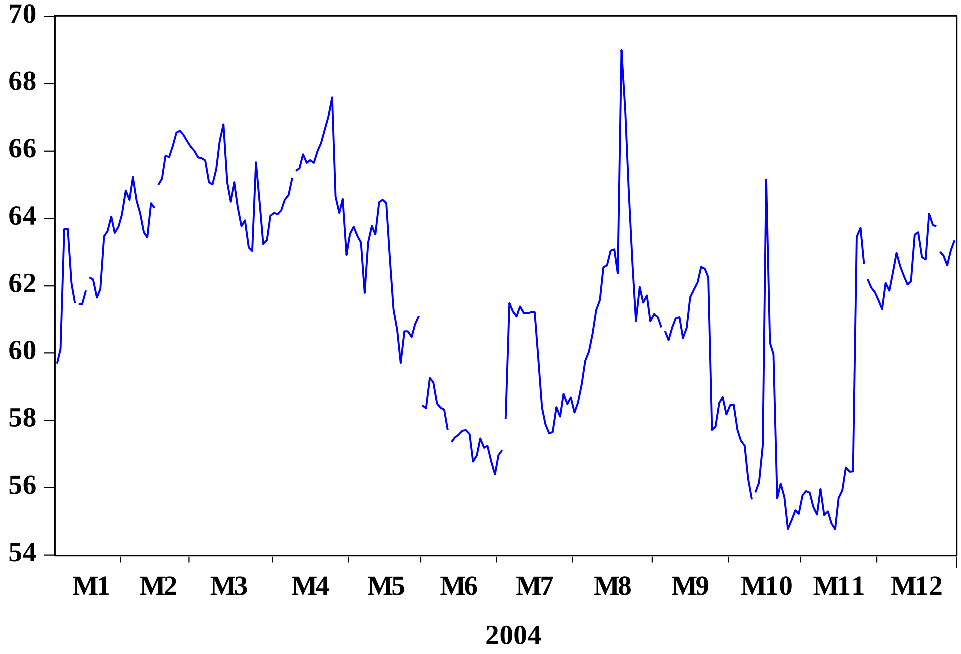
In early 2002, the deteriorating outlook for Technology puts a downward pressure on technological stock prices. From where it ends in late 2001, the total volatility spillover climbs to over 80% in mid 1st quarter. Afterwards, the total volatility spillover declines to approximately 70% in late 2nd quarter and fluctuates around there during the 3rd quarter. The total volatility spillover keeps staying high from the start of the year due to a wave of corporate scandals in several sectors. Especially, firms in Telecommunications struggle the most. The sector's biggest failure is the bankruptcy of WorldCom in July. Other notable bankruptcies regarding Telecommunications are Global Crossing in January and Adelphia Communications in late June. Besides, Qwest Communications experiences a dramatic stock collapse after escaping from the bankruptcy. Corporate scandals are also found in sectors other than Telecommunications. For instance, Utilities sees the scandal of Dynegy in May. Industrials has Tyco's scandal in June. Healthcare endures the scandals of ImClone in June, Bristol-Myers Squib in July, and Tenet in October. In reaction to the series of corporate scandals, Congress passes the legislation named Sarbanes-Oxley Act in July. Over the 4th quarter, the total volatility spillover experiences a downward movement and ends 2002 at below 55%.

3.1.1.2. The 2003 – 2004 Period

The second period from 2003 to 2004 involves the movement of total volatility spillover between 50% and 65%.

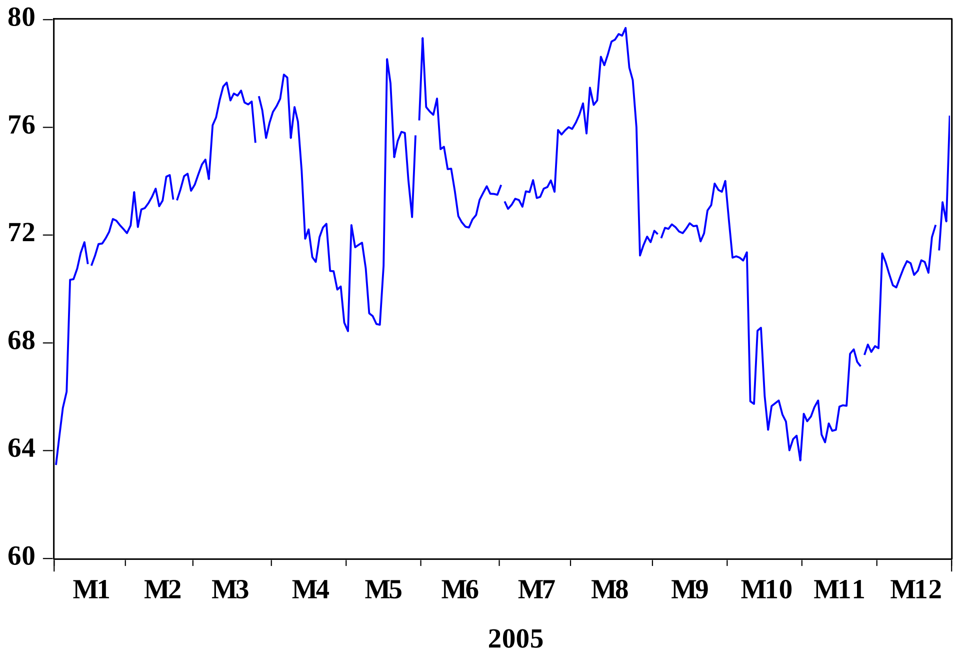


Over the full sample, 2003 is the calmest year for the total volatility spillover. During the year, unemployment remains high. It begins and ends the year at roughly the same value of 5.7%. Besides, the average oil price for the year is a high $30/b. While the first half of the 1st quarter sees the total volatility spillover fluctuate around 55%, the second half of the 1st quarter and early 2nd quarter see the total volatility spillover swing around 50%. The total volatility spillover starts moving up, breaks the 65% mark in early 3rd quarter, and exceeds 70% around mid 3rd quarter. After the high record, the total volatility spillover tumbles to about 55% and keeps moving around there through early 4th quarter. The total volatility spillover drifts upward during the 4th quarter and ends the year at above 60%. Although the U.S. invasion of Iraq from 20 March to 1 May has a moderate impact on oil prices, it does not seem to have a large effect on the total volatility spillover. The total volatility spillover ranges between 50% and 55% during that period.



2004 is another cool year for the total volatility spillover. Speculations of higher oil prices and rising interest rates account for the high total volatility spillover over the year. From the 1st quarter to mid 2nd quarter, the total volatility spillover moves between 60% and 65%. From the second half of the 2nd quarter to the end of the year, the total volatility spillover fluctuates within the 55% - 60% range. The investors are cautious in the first half of 2004. In fact, oil prices increase to $37.31/b in late April and to $39.9/b in late May from already high $32.51/b in late 2003. There are several reasons for the high total volatility spillover during the first half of 2004. In the 1st quarter, Technology struggles due to the troubles faced by Oracle and Microsoft. Besides, some large components, such as Bristol-Myers Squibb and Abbott Laboratories, disappoint the healthcare sector. Moving to the 2nd quarter, frets about mounting interest rates to erode banks returns affect big stocks in Financials such as Goldman Sachs, Citi Group, J.P. Morgan Chase, and Morgan Stanley, making losses in Financials. Top components of Utilities such as Duke Energy, Exelon, and Southern are weighed down by the uncertainties about U.S. government's regulatory. In the second half of 2004, the total volatility spillover moves wildly since the economic outlook is mixed by both positive and negative news. Especially, both oil prices and effective interest rates grow rapidly in the 3rd quarter. Interest rates are 1.26%, 1.43%, and 1.61% in the end of July, August, and September, respectively. Besides, oil price reaches $49.56/b in late 3rd quarter. In late 2004, the effective interest rate and the oil price are 2.16% and 43.36%, respectively. From the low in mid November, the total volatility spillover shoots up and ends the year at above 62%.

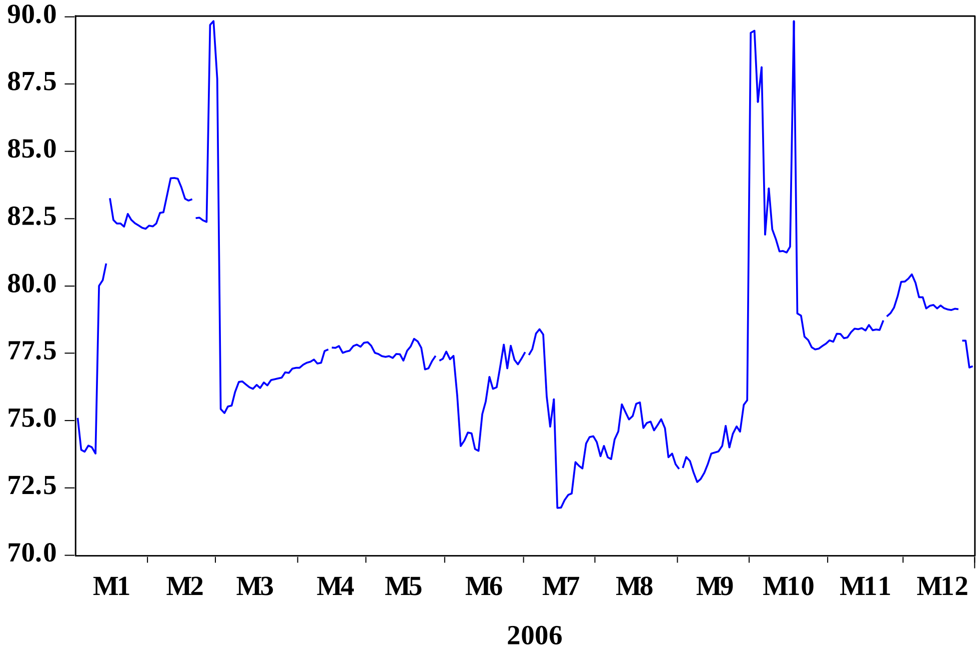
3.1.1.3. The 2005 Period



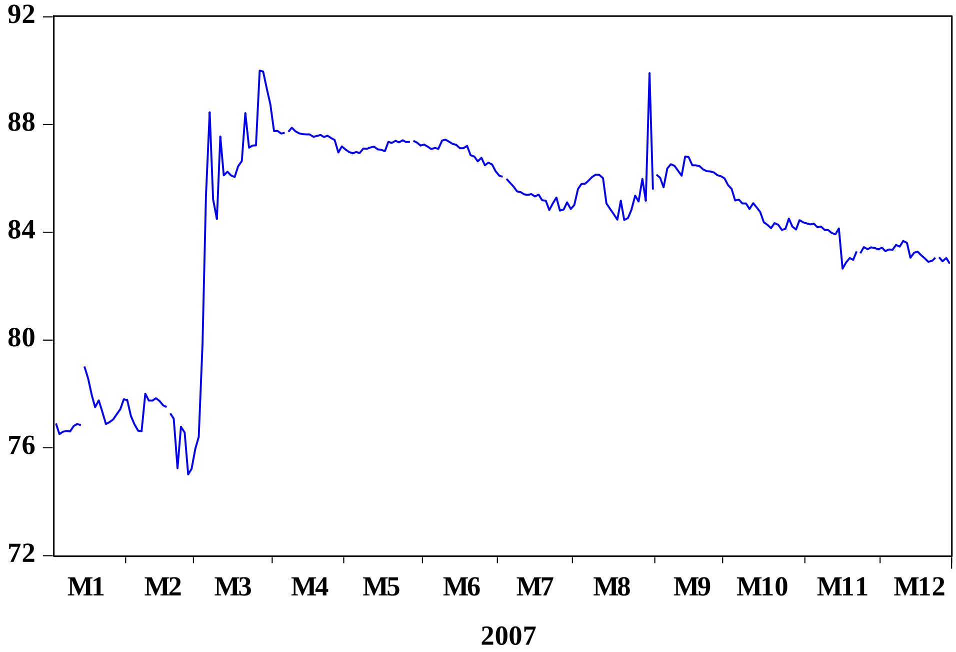
During 2005, the total volatility spillover varies within the 60% - 80% range. Oil prices and interest rates are factors which have strong impacts on the total volatility spillover during the year. Nandha and Faff (2008) show that oil price rises have negative impacts on the equity returns for all sectors except mining, and oil and gas industries. From nearly 64% at the beginning of the year, the total volatility spillover jumps to over 76% in early 2nd quarter due to the surge in oil prices. While the slight decrease in oil prices moves the total volatility spillover to above 68% in the first half of the 2nd quarter, the increase in oil prices keeps the total volatility spillover above 70% through late 3rd quarter. Obviously, the hurricane Katrina in late August leads the total volatility spillover to climb to about 80%, and the hurricane Rita in late September sends the total volatility spillover to above 70%. In fact, oil prices observed in late August and late September are $68.63/b and $66.21/b, respectively. In reaction to the oil prices decrease in the early part of the 4th quarter and oil prices increase in the latter part of the 4th quarter, the total volatility spillover tumbles to about 65% before moving up and ending the year at approximately 75%. While oil prices fluctuate over the year, the interest rates drift up continuously. In fact, the effective interest rate elevates to 4.16% in late 2005 from 2.16% in late 2004. Due to the direct impact of federal funds rate changes on revenues and costs of financial institutions, stocks of some big banks struggle amid rising interest rates. Note that bad performances of some technological stocks also contribute to the high total volatility spillover over the year.

3.1.1.4. The 2006 – 2014 Period

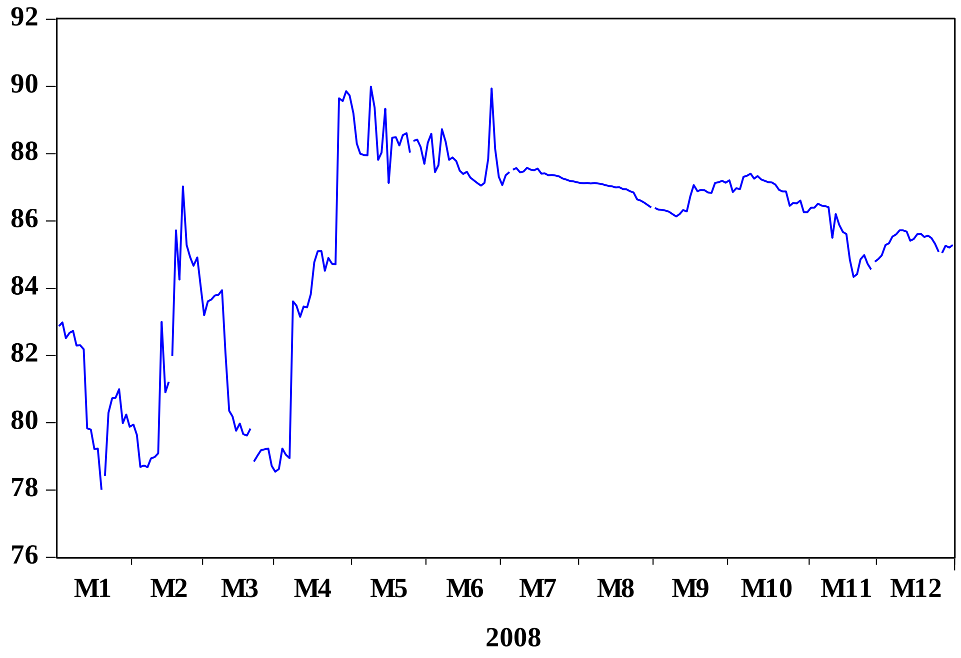
Regarding the last period from 2006 to 2014, the total volatility spillover ranges between 70% and 90%.



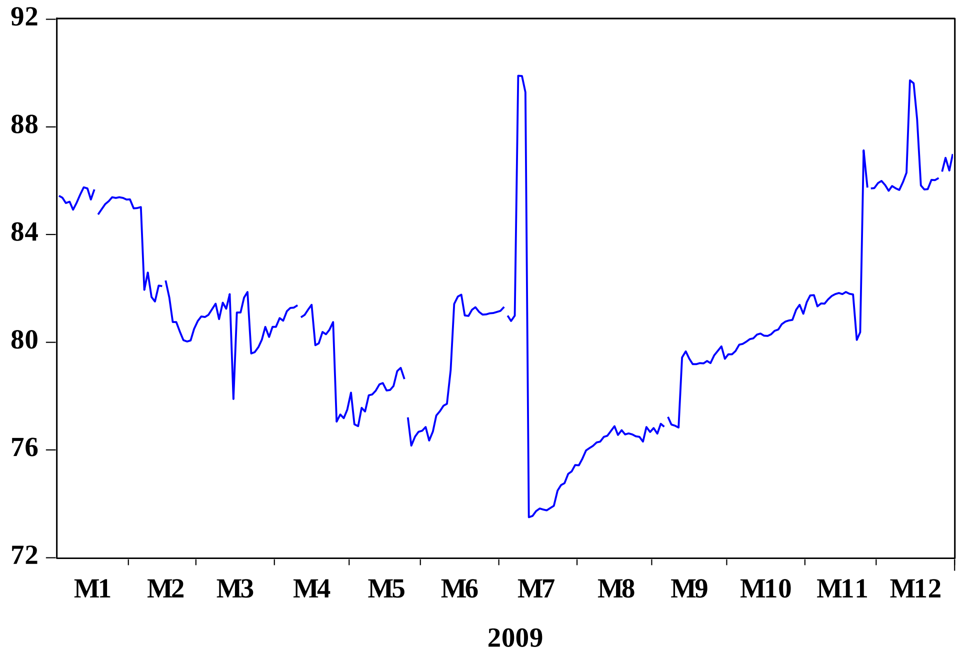
2006 can be considered the calmest year in the third period. During the first two months of the 1st quarter, the total volatility spillover moves above 80%. The period from late 1st quarter to late 3rd quarter sees the total volatility spillover fluctuate within the 71% - 78% range. The total volatility spillover remains above 75% in the 4th quarter. Although the stock market performs well in early 2006, frets about high inflation rates and concerns about the growth in corporate profits are factors that result in the high total volatility spillover in early 1st quarter. In fact, the inflation rate in late 2005 is a high 3.4%. As a routine Fed is more likely to increase the interest rates to press the inflation down. This raises another fear that Fed's hard tightening can shift the economy to a recession. Oil prices exceed the $70/b level in the 2nd and the 3rd quarters. Especially, oil prices observed in late February and late October are the lowest monthly prices over the year. Although lower oil prices ease the inflationary fears and encourage the consumer spending, volatility of Energy increases as stocks of the sector struggle. Consequently, the total volatility spillover is sent to high records.



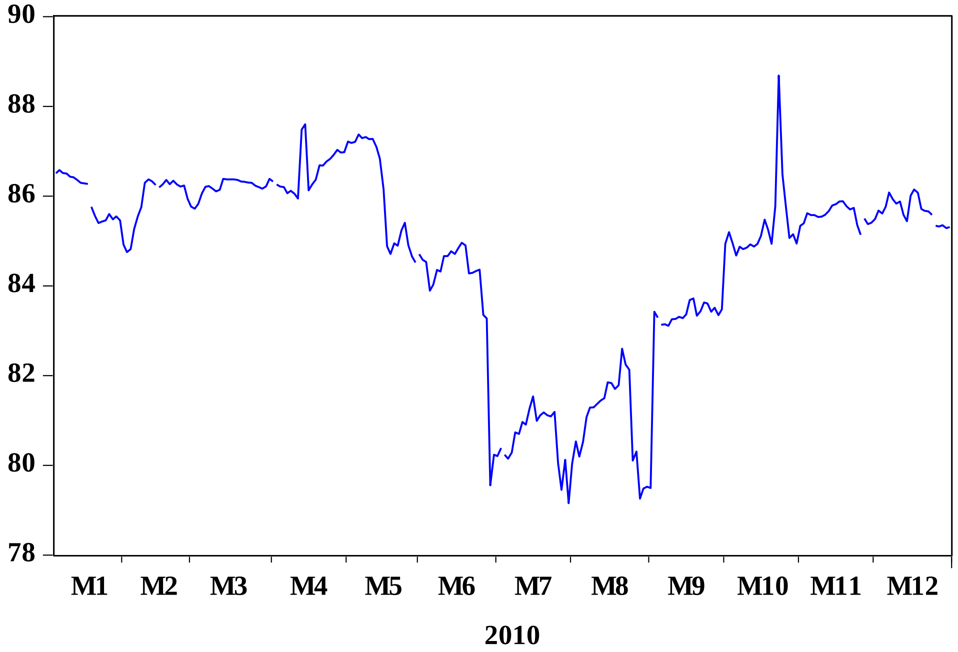
In early 1st quarter, the total volatility spillover fluctuates around 75%. Regarding the housing market, the investors concern that a loss of liquidity may push home prices down, and the downward trend then impacts the consumer spending and depresses the employment. Besides, the investors also speculate that Fed is less flexible to cut the interest rates to support the housing market amid the currently high inflation. In fact, the inflation in late 2006 is a high 3.2%. In late 1st quarter, the total volatility spillover rockets to above 85% and soars above 80% during the remaining part of the year. Understandably, the total volatility spillover movement tracks the uncertainties about increasing defaults of subprime mortgage loans. It is not until the second half of 2007 that the subprime mortgages crisis has an apparent impact on the financial markets. The subprime mortgage crisis results in huge losses on banks' balance sheets, limiting their capacities to expand credit. According to NBER, the GFC begins in December 2007.



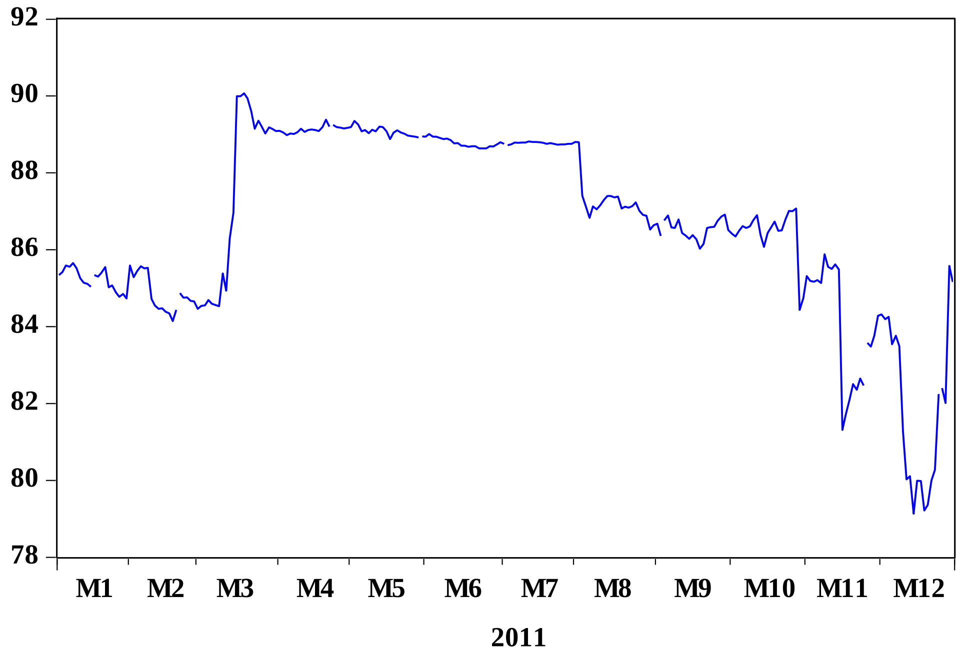
In 2008, "Financial Crisis" is the phrase which dominates the headlines. The mortgage defaults keep surging. It is interesting to consider relationship equations between banking, house prices, and unemployment rates. First, high unemployment rates equal insufficient money to obligate the mortgages. Second, higher un-paid mortgages equal greater delinquencies and foreclosures. Third, higher mortgage defaults equal lower house prices. In combination, the sum of higher mortgage defaults and lower house prices equals increasing banking troubles. As a result, Financials is tied with the rising unemployment rates. January and February see the declines in unemployment rates, interest rates, and house prices while March experiences the increases in these indicators. Besides, oil prices keep drifting upward during the 1st quarter. As a result, the total volatility fluctuates wildly within the 78% - 86% range in the 1st quarter. The total volatility spillover soars above 85% in the last three quarters. Oil prices keep moving up in late 2nd quarter, heightening the inflationary concern and damaging the consumer spending. In reaction, the total volatility spillover keeps surging. In the 3rd quarter, oil prices remain high, unemployment increases slightly, and house prices drop. Apparently, September 2008 shocks the financial markets as Financials endures dramatic troubles and collapses of several big banks, notably the bankruptcy of Lehman Brothers. Over the 4th quarter, rising unemployment rates and plunging house prices eclipse Fed's attempt in lowering the interest rates. Besides, the sharp plummet in oil prices impacts Energy. In late 2008, the unemployment rate, interest rate, oil price, and house price are 7.3%, 0.16%, \$44.6/b, and \$175,700, respectively.



Regarding the total volatility spillover movement, the plot in the first half of 2009 exhibits a downward trend while the plot in the second half of the year shows an upward trend. Generally, from where it ends in late 2008, the total volatility spillover steps down and down to hit the bottom of the year in early 3rd quarter. This coincides with the fact that the GFC is over in late 2nd quarter. The first half of the year sees the recovery in house prices. From \$164,600 in early 2009, house price increases to \$169,999 in late 1st quarter and to \$181,800 in late 2nd quarter. The oil prices rebound rapidly as well, reaching \$49.64/b in late 1st quarter and \$69.82/b in late 2nd quarter. However, rising unemployment rates reflect a troubled labor market which concerns the investors. Especially, the unemployment rate in late June reaches 9.5%. From the bottom, the total volatility spillover steps up gradually during the second half of the year. More precisely, the total volatility spillover flies above 85% in late 2009. Although effective interest rates are maintained around 0% level, worries about falling house prices, high oil prices, and alarming unemployment rates drive the total volatility spillover up. House price, oil price, and unemployment rate in late 2009 are \$170,700, \$79.39/b, and 9.9%, respectively.

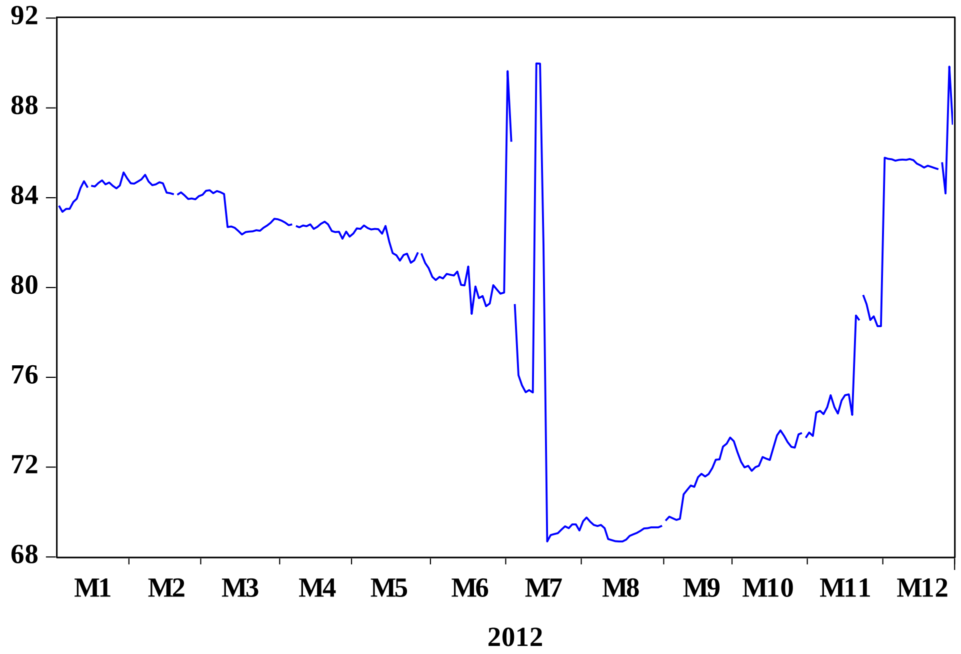


In the first half of 2010, the total volatility spillover moves around where it ends in late 2009, say 85%. The 2nd quarter coincides with the 6 May Flash Crash. During the period from late June to late August, house prices rebound to above \$175,000 (from a low \$164,900 in early 2010) while employment rates drop to below 9.5% (from a high 9.8% in early 2010). The 3rd quarter involves the total volatility spillover movement around 80%. In late 3rd quarter, the total volatility spillover surges back to about 85% and keeps staying around there through the end of the year. The total volatility spillover is high because economic indicators are not much better to boost the confidence of investors. In late 2010, the unemployment rate stays as high as 9.3%, the house price falls to \$168,800, and oil price turns to a new high \$91.38/b (from \$72.85/b in early 2010).

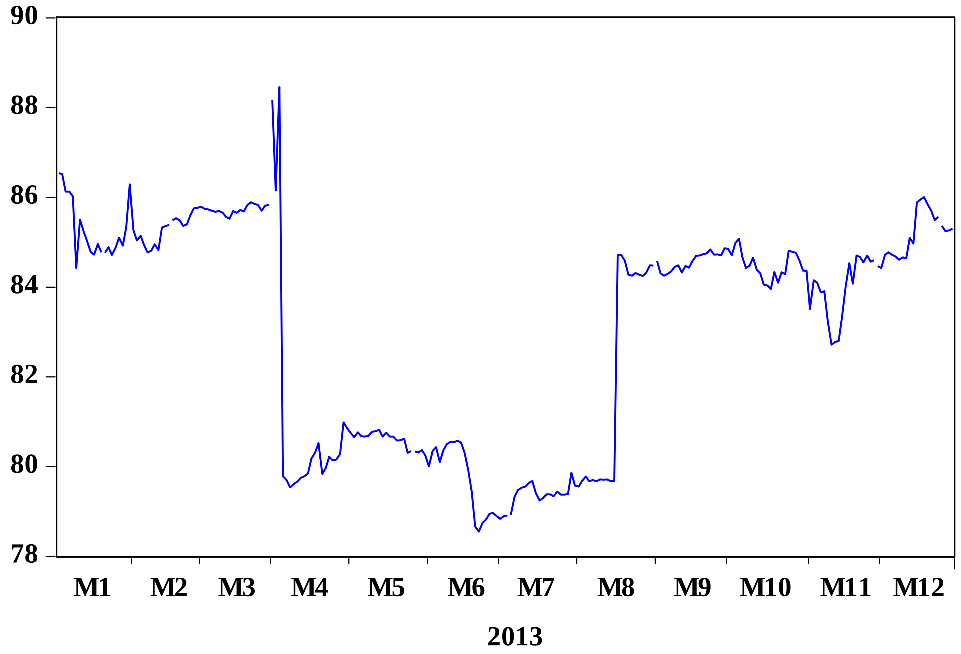


In January, housing prices touch the lows of 2009, and energy prices keep increasing. The total volatility spillover stays around 85% in early 1st quarter. After that, it reaches about 90% in late 1st quarter and stays within the 85% - 90% range through early 4th quarter. The continuation of negative economic news in the first two quarters panics the investors and boosts the total volatility spillover to new highs. In the 2nd quarter, oil prices remain high despite having come off the peaks. The jobs creation and the housing market see new lows. The 3rd quarter coincides with the debt ceiling impasse. According to the Siddiqui (2013), around the debt ceiling impasse, the consumer and business confidences fall sharply, the financial markets go through stress, and the job growth slows. On 5 August, S&P downgrades U.S. credit rating for the first time in history. Unemployment is still high due to a slow job creation. In fact, U.S. stock market starts falling from August. Housing remains depressed, and foreclosures continue between bank and customers. A double-dip recession is speculated to happen. Regarding Financials, the investors fret about banks' exposure on possible defaults in Greece as well as in other European nations. Notably, Bank of America has the worst performance. In response, the Federal Reserve decides to keep interest rates low through at least mid 2012.

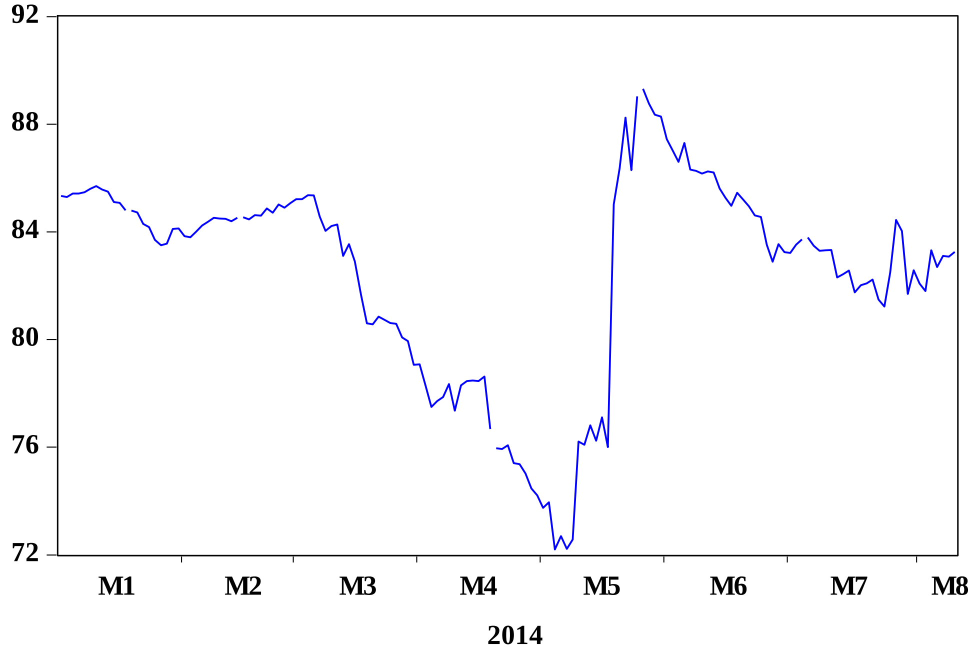
In late 4th quarter, the total volatility spillover drops to about 80% before ending the year at about 85%.



From about 84% at the beginning of 2012, the total volatility spillover stays above 80% till late 2nd quarter. The year starts with optimistic economic data such as: unemployment drops, worries about Europe fade away, and housing improves. However, high oil price is a factor that keeps the total volatility spillover high in the 1st quarter. Next, a wave of bad news in the 2nd quarter holds the total volatility spillover high. Both the economic growth and the job creation decelerate. Also, negative news comes from financial firms, notably JPMorgan Chase. Although tumbling energy prices refresh the economy, energy companies struggle. In terms of Technology, Facebook's IPO on 18 May makes the market more bustling. Despite being expected to perform well, this new firm has a poor performance. The total volatility spillover falls to below 70% in early 3rd quarter and stays there for a while. The short-lived decline is resulted from positive economic data. Afterwards, the total volatility spillover starts moving upward in late 3rd quarter and mounts to about 85% in late 4th quarter. The presidential election and the uncertainties surrounding the fiscal cliff are factors which control the headlines during the 4th quarter and have strong impacts on the total volatility spillover. According to Calmes (2012), the fiscal cliff in 2012 refers to more than $500 billion in tax increases and across-the-board spending cuts (budget sequestration) scheduled to take effect after 1 January 2013 - for fiscal year 2013 alone - unless Mr. Obama and Republicans reach an alternative deficit-reduction deal. The speculation that President Obama fails to retain the White House concerns the investors. Furthermore, the uncertainties of the fiscal cliff impact investment decisions. Companies issue special dividends around the year-end to prevent an undesired high tax on dividend income (see (McGranahan & Nohel, 2014)) or wait until the cliff issue is resolved to make decisions on capital expenditures. Davig and Foerster (2014) show that increases in economic uncertainty press the investment and the employment down. Eventually, the unresolved fiscal cliff boosts the total volatility spillover to above 88% in late 2012.



It is apparent to recognize three different marks around which the total volatility spillover fluctuates during 2013. Generally, the total volatility spillover moves above 85% in the 1st quarter, fluctuates around 80% in the 2nd quarter and in the first half of the 3rd quarter, and drifts around 85% in the remaining time of the year. On 1 January, Congress avoids the fiscal cliff by passing the budget deal to raise taxes but delaying the budget sequestration until 1 March 2013. When taxes hike is eased, the investors are confident to pour money back into equities. However, the uncertainties surrounding the budget sequestration contribute to the high total volatility spillover in the 1st quarter. Regarding negative news, Apple's trouble contributes to volatility of Technology. In the 3rd quarter, as Treasury yield goes up, stocks of Telecommunications and Utilities struggle. In fact, the 10-Year Treasury rate increases to above 2.58% in early 3rd quarter from 1.91% in early 1st quarter. Furthermore, the debt ceiling debate also keeps the total volatility spillover high in the 3rd quarter. According to Popper (2013), most economists and investors view the debt ceiling as a much more significant issue for the economy, with the potential to set off a global financial crisis. In fact, the debt ceiling impasse contributes to financial market disruptions, lower confidence, weaker economic expansion, and higher uncertainty. In the remaining part of the year, the event that impacts the total volatility spillover is the partial government shutdown. Although the impact of the shutdown on stocks is unclear, the shutdown attracts the attention of investors during October and has a substantial impact on the economy.



In the first two months of 2014, the total volatility spillover moves around 85%. There are some events that account for the high total volatility spillover. For instance, the U.S. economy undergoes one of the harshest winters in decades whose effects impact several sectors and economic indicators. Particularly, many stocks in Consumer Services struggle amid the severe winter conditions. Moreover, the market is volatile in late January due to inflationary fears. With a large proportion of long-term debt in nature, Telecommunications struggles from the speculation regarding rising interest rates. Afterwards, the total volatility spillover starts its downward movement in early March and drops to under 75% in early May. Although the volatility spillover drifts lower, the total volatility spillover is still considered high. According to Davidson (2014), Fed diminishes the forecast for 2014 GDP growth to 2.1% - 2.3% from 2.8% - 3.0%. Also, Bank of America and JPMorgan Chase & Co contribute to the losses in Financials. Moving further, a sharp plunge in prices of oil and natural gas boosts the total volatility spillover to about 88% in late May. Following the sharp jump, the total volatility spillover fluctuates below 85% through the end of the sample. It is Energy which struggles the most and holds the total volatility spillover from falling down during the second half of the year. The sharp plunge in oil prices is well-explained by Global Economic Prospects (2015) and E.L (2014). In fact, oil prices plummet from $106.07/b in late June to $53.45/b in late 2014. Note that the downward trend in oil prices is ongoing at the time this paper is written.

In summary, the dynamic total volatility spillover, which captures how connected the ten sectors are, is time-varying and sensitive to market and economic events. As discussed, the ten sectors have become more connected since late 2006. This is reasonable due to the increased interdependence between sectors. According to Burns, Peters, and Slovic (2012), the way market participants as well as ordinary citizens perceive risk has been changed by the GFC. Moreover, the investors are more cautious to not only domestic but also external news, in both sectoral and national terms.

3.1.2. Robust Tests

This section discusses the robustness of the total volatility spillover to the choices of lag, forecast horizon, and window width.

[Insert Figures 2.1, 2.3, 2.4, 2.5, 2.6 around here]

Besides the main test (with p = 3 lags, H = 12 days, and W = 100 days), there are nine additional dynamic tests. In the first four additional tests, the choices of forecast horizon and window width are constant at 12 days and 100 days, respectively. Whereas, the choice of lag varies from 1 lag to 5 lags except 3 lags. The rolling total volatility spillovers of the first four additional tests and the main test are presented in Figure 2.5. Apparently, the total volatility spillover estimated by larger p tends to stay higher. This suggests that the longer lag, the higher total volatility spillover. However, the total volatility spillover movement looks the same in all the tests, signaling that the total volatility spillover is robust to the choice of lag. Since the central interest is to explore trends, cycles, and bursts, the test for an appropriate lag at the beginning is not necessary. In the next two additional tests, the lag of 3 days and the window width of 100 days remain unchanged. Whereas, the forecast horizons are 6 days for the first test and 18 days for the second test. Obviously, the total volatility spillover movements of these two tests and the main test take after each other in Figure 2.6, suggesting that the total volatility spillover is also robust to the choice of forecast horizon. In the last three additional tests, the lag of 3 days and the forecast horizon of 12 days are constant while the window width varies. Figures 2.1, 2.3, and 2.4 exhibit the outcomes for the tests estimated by the window widths of 75 days, 150 days, and 200 days, respectively. It is apparent that the trends, cycles, and bursts in the total volatility spillover are similarly tracked in these three tests.

However, Figure 2.4 reflects that a larger window width tends to result in a less dynamic plot. This reasons why the 100-day window width is set for the main test.

3.2. Rolling Total Directional Volatility Spillover

3.2.1. Total Directional Volatility Spillover from the Others to Each of Ten Sectors (From-Spillover)

Since the sum of the from-spillover and the own-shock of a given sector equals 100%, the two shock components are negatively correlated. In other words, an increase in the own-effect leads to a decrease in the cross-effect, and vice versa. Given a sector, the from-spillover is only useful to determine periods of high own-effect over time. Note that periods of high own-effect often coincide with periods during which the to-spillover experiences significant bursts. In such the indirect ways, sections 3.2.2 and 3.3.1 discuss these periods well.

[Insert Figure 3 around here]

3.2.2. Total Directional Volatility Spillover from Each of Ten Sectors to the Others (To-Spillover)

The volatility shock of a sector tends to spread over other sectors in various ways and at different degrees. On the time-varying basis, the to-spillover is informative about how dynamic and how frequent the transmitted volatility shock from a given sector to the others is over time. In this section, the sectors presentation follows the ascending order of unconditional to-spillover measures shown in the Table 4A.

[Insert Figure 4 around here]

3.2.2.1. Consumer Goods - IYK

Figure 4.7 illustrates the change in IYK's to-spillover. Generally, the to-spillover of IYK is relatively low over the examined sample. The plot of IYK's to-spillover has no significant pattern during the 2001 Recession and the GFC. However, the to-spillover peaks at about 70% in mid 2004 and at about 75% in early 2005. Especially, the to-spillover surges to about 90% in the second half of 2012 and in 2013. While late 2012 coincides with the uncertainties surrounding the fiscal cliff debate, 2013 coincides with the budget sequestration and the debt ceiling debate. As estimated in the static analysis, the unconditional to-spillover of IYK is 17.1%. This matches the dynamic point of view.

3.2.2.2. Healthcare - IYH

Figure 4.5 gives the to-spillovers for IYH. Similar to IYK, the to-spillover of the sector is quite low over the examined sample. The plot of IYH's to-spillover is relatively flat over the 2001 Recession and the GFC. Being considered defensive in nature, IYH is apart from cyclical and macroeconomic effects. Nevertheless, the to-spillover of IYH rockets to over 200% in 2002 due to the scandals of its components. Also, the to-spillover surges to above 75% in 2011 and to approximately 100% in early 2013. While the surge in 2011 coincides with the debt ceiling debate and the August stock markets fall, the surge in early 2013 is resulted from the activation of the budget sequestration. Furthermore, IYH's to-spillover mounts to over 170% in late 2013 and in early 2014. The dramatic surges in late 2013 and in early 2014 coincide with the execution of the Affordable Care Act. In fact, U.S. residents are required to register for the health care insurance before late December without penalty. Also, IYH's to-spillover mounts to about 100% in late 2014. Following the static analysis, IYH's unconditional to-spillover is 21.3%.

3.2.2.3. Consumer Services - IYC

Figure 4.2 presents the to-spillovers for IYC. Opposite to IYK, IYC comprises companies whose businesses are sensitive to economic news and market cycles. Apparently, the to-spillover of IYC exhibits the cyclical trend by moving up and down over the examined sample. In terms of the 2001 Recession, the to-spillover climbs to over 60% at the beginning of the recession and maintains the value of above 50% over the next two quarters. Regarding the GFC, the low to-spillovers of IYC during this period are higher than the lows observed in the period prior to the crisis. Especially, the to-spillover boosts to above 80% in early 2008. It is not difficult for IYC's to-spillover to rocket. There are several other peaks such as above 100% in the 3rd quarter 2010, above 130% in late 2012, above 100% in late 2013, and above 100% in late 2014. Note that IYC's unconditional to-spillover is 41.1%. This is bias to the latter part of the full sample since the to-spillover of IYC tends to be larger after 2009.

3.2.2.4. Utilities - IDU

Figure 4.1 shows the to-spillovers for IDU. Although IDU is one of the three examined defensive sectors, the movement of IDU's to-spillover looks wild. The burst in IDU's to-spillover often occurs. Also, the bursting to-spillover tends to be higher than 100%. Especially, late 2006 and early 2007 see the to-spillover surge to above 400%. Following the static analysis, the average to-spillover of IDU over the full sample is 53.9%. It appears that the index balances high to-spillovers in bursting periods and low to-spillovers in normal periods.

3.2.2.5. Industrials - IYJ

Figure 4.6 exhibits the variation in IYJ's to-spillover. Similar to IYC, the to-spillover of IYJ reflects the sector's cyclical feature well. IYJ's to-spillover moves to a new level after 2006. Each of the low to-spillovers after 2006 is higher than any low to-spillover observed before 2006. Since the sector performance goes with the economy health, the impact of the GFC on IYJ's to-spillover is quite clear. Especially, the surge to above 140% during 2010 and during 2011 also reflects the sensitivity of the sector to U.S. economic events. Overall, IYJ's to-spillover is cyclical, and the magnitude of the spillover is moderate.

3.2.2.6. Technology - IYW

The to-spillovers of IYW are depicted in Figure 4.9. The sector is potential to show bursts in its to-spillover. IYW's spillover tends to fluctuate around 100%. It is realized that IYW's to-spillover rockets to over 500% in early 2001 and remains substantially high during the year. The unconditional to-spillover of IYW from 2001 to 2014 is 78.1%. This suits the dynamic perspective.

3.2.2.7. Telecommunications - IYZ

The to-spillovers of IYZ are plotted in Figure 4.10. The clear burst in IYZ's to-spillover can be easily realized in the period from early 2001 to mid 2004. The to-spillover stays around 200% during this long period. The to-spillover also surges to above 200% during 2012 and during 2013. Apart from the bursts, IYZ's to-spillover tends to stay below 50%. The unconditional to-spillover of 111.1% given by the static analysis is bias to the burst in early 2000s. Thus, it is not fair to conclude that IYZ contributes largely to volatility of other sectors over time. On the dynamic perspective, the to-spillover of IYZ is not consistent. However, the sector is potential to transmit its volatility to the others at a large spillover magnitude.

3.2.2.8. Financials - IYF

Figure 4.4 shows the to-spillovers for IYF. Obviously, the to-spillover of the sector explodes during the GFC. While IYF's to-spillover stays below 50% prior to 2007, it turns to a new high after the crisis by fluctuating between 50% and 100%. The unconditional to-spillover of the sector is 126.1%. This is apparently bias to the to-spillover after 2007.

3.2.2.9. Materials - IYM

Figure 4.8 describes the movement of IYM's to-spillover. Since IYM is a highly cyclical sector, its to-spillover reflects that characteristic well. The highs and the lows of IYM's to-spillover are relatively stable. Apparently, IYM's to-spillover tends to be larger in the period from 2007 to 2012. This period coincides with several significant economic and market events (see section 3.1). As shown in the static analysis, IYM's unconditional to-spillover is 130%.

3.2.2.10. Energy - IYE

Figure 4.3 provides the to-spillovers for IYE. The sector experiences significant bursts in 2005 and in the latter part of 2014. Also, IYE's to-spillover appears to be larger from 2005. Over years, there is no sign of subsidence in IYE's to-spillover. In other words, IYE tends to have a high and consistent to-spillover over time. According to the static analysis, IYE ranks first in having the highest unconditional to-spillover of 135%.

In summary, Consumer Goods, Consumer Services, and Healthcare have the lowest to-spillovers while Energy and Basic Materials experience the largest to-spillovers over time.

3.3. Rolling Net Total Directional Volatility Spillover

The rolling net total directional volatility spillover (net-spillover) investigates significant bursts in volatility transmission between a given sector and the other nine sectors, in net total terms. This section contains two separate parts. The first part provides the general information about the net-spillover for each of the ten sectors over the full sample. The second part focuses on the 2001 Recession and the GFC so as to discover how the involved sectors contribute to volatility of the system during highly turbulent times. Figure 5 presents the net-spillover plots for ten sector ETFs. In each sub-figure, the positive net-spillover indicates the sector's role as a net volatility transmitter while the negative net-spillover suggests the sector's role as a net volatility receiver.

[Insert Figure 5 around here]

3.3.1. Rolling Net Total volatility spillover by sector ETFs

On the time-varying basis, this first part discusses the bursts in volatility transmission of each of the ten sectors. The sectors presentation follows the ascending order of unconditional net total volatility spillover measures shown in Table 4A.

3.3.1.1. Consumer Goods - IYK

Figure 5.7 illustrates the change in IYK's net-spillover. Overall, IYK has only one considerable episode of positive net-spillover to other sectors. The episode takes place in the second half of 2012. During this episode, IYK transmits volatility to other sectors at a general magnitude of about 50%. As discussed, this episode coincides with the increasing concern surrounding the fiscal cliff debate. Most of the time, IYK takes the role as a net volatility receiver. The general magnitude of IYK's total received volatility is about 90%, and no marked difference during the 2001 Recession and the GFC is detected. Understandably, as being considered defensive or non-cyclical, volatility of stock prices of IYK's constituents is relatively less certain. As a result, the to-spillover rarely surpasses the corresponding from-spillover so as to give the positive net-spillover. According to the static analysis, IYK has the lowest value of unconditional net-spillover over the full sample, say negative 78.7%. This once confirms that IYK tends to be the strongest net volatility receiver over time.

3.3.1.2. Consumer Services - IYC

Figure 5.2 presents the net-spillovers for IYC. In most of the observations over the examined sample, IYC is a net receiver of volatility at the general magnitude of about 70%. Episodes during which IYC transmits volatility to other sectors are found in the 4th quarter 2002, the 2nd quarter and the 3rd quarter 2003, the 3rd quarter 2006, the 2nd quarter and the 3rd quarter 2010, the 4th quarter 2012, the 4th quarter 2013, and the latter part of 2014. These episodes are all short-lived, and the transmitted volatilities are at small magnitudes since the to-spillovers do not constantly and far exceed the respective from-spillovers. Generally, the magnitude of spillover received by IYC varies over time. As mentioned in the static analysis, IYC is a net volatility receiver by having an average net-spillover of negative 51.1% over the full sample. This is relatively true on the dynamic perspective.

3.3.1.3. Healthcare - IYH

Figure 5.5 gives the net-spillovers for IYH. Overall, IYH has two substantial episodes during which it contributes to volatility of the other sectors. The first episode begins in mid 1st quarter 2002 and ends in early 3rd quarter 2002. The general magnitude of the transmitted volatility in this exceptional episode is above 200%. In 2002, Healthcare is one of the troubled sectors in the market. In fact, the sector endures several corporate scandals, notably scandals of Tenet, Bristol-Myers Squib, and ImClone. The second episode lasts from late 3rd quarter 2013 to mid 2nd quarter 2014. The general magnitude of the transmitted volatility is above 100%. During this episode, stock prices of IYH's components are volatile because healthcare consumption rises following the execution of Affordable Care Art. According to Furman (2013), the critical reforms under Affordable Care Art result in dramatic slowdown in the healthcare cost growth, meaning less pressure on employers and the federal budget, and more take-home pay for families. Over the full sample, most of the time IYH is a net volatility receiver. The general volatility shock received by IYH is around 80%, and no marked pattern is found during the turbulent times. Understandably, IYH is considered defensive in nature as the demand for healthcare products and services is inelastic. Following the static analysis, IYH exhibits the unconditional net total volatility spillover of negative 72.2% over the full sample. Jointly, IYH tends to receive more volatility shocks than it transmits over time.

3.3.1.4. Industrials - IYJ

Figure 5.6 exhibits the variation in IYJ's net-spillover. IYJ experiences one major episode during which its spillover to other sectors is larger than that in the reverse direction. The episode lasts from late 4th quarter 2009 to early 4th quarter 2011. The general magnitude of the transmitted spillover during this episode is about 50%. However, consider the whole plot, what attracts the reader's attention the most is exactly the area below the horizontal axis. Similar to IYC, the magnitude of IYJ's received volatility fluctuates over time. It has been shown that IYJ has an unconditional net-spillover of negative 31.8% over the full sample, signaling its role as a net volatility receiver. Definitely, the sector tends to be a net volatility receiver over time.

3.3.1.5. Utilities - IDU

Figure 5.1 shows the net-spillovers for IDU. There are five major episodes of net volatility spillover taking place from IDU to other sectors. The first episode begins in early 2nd quarter 2002 and ends in late 3rd quarter 2002. In fact, the scandals of Dynegy

Inc. in May and Duke Energy in July contribute to IDU's volatility. The second episode takes place in 2004. The third episode starts in early 4th quarter 2006 and finishes in late 2nd quarter 2007. The fourth episode initiates in late mid 2nd quarter 2009 and completes in mid 3rd quarter 2009. The last episode includes two sub-episodes: one spans from late April 2013 to late June 2013, and the another takes place from late July to late September 2013. Most of the episodes coincide with no specific market events. Although having several episodes of positive net-spillover, IDU's contribution to volatility of the other sectors is not consistent. This is because the sector is defensive in nature. Furthermore, most of the observations during the examined sample see IDU take the role as a net volatility receiver. The general magnitude of IDU's received volatility is around 80%. Remember that the average net total volatility spillover of IDU from 2001 to 2014 is a negative 31.1%. This once confirms that IDU tends to be a net volatility receiver over time.

3.3.1.6. Technology - IYW

The net-spillovers of IYW are depicted in Figure 5.9. From the start of the sample to mid 1st quarter 2002, IYW transmits volatility to other sectors. Following the reversed transmission between mid 1st quarter and late 2nd quarter 2002, IYW is a net volatility transmitter to other sectors untill mid 2nd quarter 2005. Afterwards, IYW continues to transmit volatility to other sectors from early 2nd quarter 2005 to early 1st quarter 2006 and from mid 1st quarter 2006 to late 3rd quarter 2006. Between late 2006 and the first half of 2009, IYW receives volatility from other sectors. In the remaining time, apart from negligibly reversed transmissions, IYW sees four more main episodes during which its gross to-spillover beats the gross from-spillover: from early 2nd quarter 2009 to late 3rd quarter 2010, from mid 4th quarter 2011 to late 4th quarter 2012, from late 3rd quarter 2013 to mid 4th quarter 2014, and from late 3rd quarter 2014 to the end of the sample. As discussed, the burst of internet bubble has a strong impact on IYW's volatility in early

2000s. Moreover, IYW is strongly affected by the GFC. The magnitude of received volatility in the early part of the crisis is between 0% and 30%. However, around the height of the crisis (around September 2008 or in late 3rd quarter 2008), the magnitude of received volatility increases up to 60%. On the unconditional basis, IYW has a net total volatility spillover of 25.5% over the full sample. The sector is considered a potential net volatility transmitter over time.

3.3.1.7. Telecommunications - IYZ

The net-spillovers of IYZ are plotted in Figure 5.10. It is apparent to identify three key episodes of IYZ's positive net-spillover. The first episode begins in early 2nd quarter 2001 and ends in mid 4th quarter 2004. Generally, the net-spillover fluctuates around 200% during this episode. In 2001, several Telecommunications' firms disappoint the investors by making corrections to previous earnings statements and revising downward their earnings forecasts. IYZ's net-spillover surpasses above 200% during 2002. Over the examined sample, 2002 is the worst year to Telecommunications' investors. The uncertainties surrounding the firms' earnings and corporate scandals make the sector struggle. Especially, the bankruptcy of WorldCom shocks the industry. Moreover, several other bankruptcies are found, notably bankruptcies of Global Crossing and Adelphia Communications. Also, Qwest Communications endures a stock collapse after escaping from the bankruptcy. The collapse of Telecommunications is resulted from the extreme speculative investment in the past. It is not until late 2nd quarter 2004 that the net-spillover falls to 0% benchmark. Volatility remains high in the first half of 2004 although the sector is recovering. The second episode takes place from early 3rd quarter 2012 to mid 4th quarter 2012. This episode experiences good news in Telecommunications. The sector outperforms the market due to the sharp growth in smartphones and tablets which boosts data consumption exponentially and finally heats up the need for wireless spectrum. The last episode starts in early 2nd quarter 2013 and finishes in mid 3rd quarter 2013. The sector is volatile during this episode due to the speculation of rising interest rates. Apart from the discussed episodes, episode from early 2005 to early 2012 shows the reverse role of IYZ, a net volatility receiver. The general magnitude of volatility received by IYZ is about 70%. Following the static analysis, IYZ's unconditional net total volatility spillover is 55.7%.

3.3.1.8. Materials - IYM

Figure 5.8 describes the movement of IYM's net-spillover. The sector goes through six crucial episodes of positive net-spillover to other sectors. The first episode takes place from mid 1^{st} quarter 2003 to late 2^{nd} quarter 2003. The second episode lasts from early 4^{th} quarter 2004 to early 2^{nd} quarter 2005. The third episode occurs in the late 4^{th} quarter 2005 and ends in late 2^{nd} quarter 2006. The fourth episode initiates in early 1^{st} quarter 2007 and completes in mid 4^{th} quarter 2008. The fifth episode spans from mid 1^{st} quarter 2009 to late 3^{rd} quarter 2012. The last episode commences in mid 4^{th} quarter 2012 and lasts through mid 2^{nd} quarter 2013. Obviously, most of the time IYM is a net transmitter of volatility to other sectors. Also, the sector tends to come back quickly as a net volatility transmitter whenever its role is reversed. As discussed in the static analysis, IYM has the third largest unconditional net total volatility spillover of 56%. In short, IYM is one of the strongest net volatility transmitters over time.

3.3.1.9. Financials - IYF

Figure 5.4 shows the net-spillovers for IYF. Overall, there are five significant episodes during which IYF is a net transmitter of volatility to other sectors. The first episode takes place between mid 1^{st} quarter and mid 2^{nd} quarter 2005. The second episode lasts from late 2^{nd} quarter 2007 to early 3^{rd} quarter 2009. The third episode begins in mid 4^{th} quarter 2009 and ends in early 4^{th} quarter 2010. The fourth and the fifth episodes occur in the second half of 2011 and in the first half of 2013, respectively. By struggling the most during the GFC, IYF is the largest contributor of volatility to other sectors during the crisis. Moreover, the sector also struggles due to strains surrounding the European Sovereign Debt Crisis. It is interesting to go through three tough episodes during which IYF struggles and discover how IYF's net-spillover reacts to dismal news.

Let's first consider the episode from late 2nd quarter 2007 to early 3rd quarter 2009. Apparently, "Subprime Mortgage Crisis" is the phrase which dominates 2007. Over the first half of the year, problems regarding the increased subprime mortgage loan foreclosures mostly impact the subprime mortgage markets. As the credit quality in the market continues to deteriorate and losses elevate around the middle of the year, the investors start withdrawing from the structured credit products and from risky assets. In late 2nd quarter 2007, the strains emerge in the leveraged syndicated loan market. In August 2007, the strains spread over the assetbacked commercial paper as well as the term bank funding markets. Especially, in the 3rd quarter of 2007, Fannie Mae and Freddie Mac issue additional equity due to their sizable losses on mortgage portfolios and credit guarantees. From the 0% benchmark in early June 2007, the net-spillover increases gradually and stays around 50% through mid July 2007. The net-spillover then surpasses 100% in late July 2007 and peaks at over 200% in mid August 2007 before hitting the 0% benchmark in late August 2007. Afterwards, the net-spillover immediately mounts to 50% again and respites around there over September 2007 and the first half of October 2007. In the last quarter of 2007, the short-term funding markets experience downward pressures amid news about larger-than-expected losses at several financial firms and a weak economic outlook. In reaction to the intensified financial strains and high market volatility, the net-spillover jumps to over 100% in mid October 2007 and swings below 150% till the year-end. According to NBER, the GFC initiates in December 2007. Moving to the first part of 2008, mortgage defaults keep surging, and the anxiety about credit risk intensifies. Amid heightening strains in financial conditions, the net-spillover moves widely. From about 150% at the beginning of 2008, the net-spillover drifts upward and reaches 300% in mid January 2008. After fluctuating around there for a while, the net-spillover climbs to over 400% in late February 2008. On 16 March 2008, Bear Stearns experiences a liquidity crisis and eventually gets acquired by JPMorgan Chase & Co. In June, following the fact that mortgage portfolios of Fannie Mae and Freddie Mac are at risk of shorting capital to offset the important losses, stocks of these government-sponsored enterprises plunge substantially. These events do impact the movement of IYF's net-spillover. During March 2008, the net-spillover moves within the 300% - 400% range before dropping to below 50% in late April 2008. The net-spillover surges back to 300% in early May 2008. The net-spillover then fluctuates between 300% and 400% before plunging to 100% in early June 2008 and to 0% benchmark in late June 2008. Not so long after the subsidence, the net-spillover jumps back to 100% and stays around there through early November 2008. From 100% mark, there is no sign of decline in IYF's net-spillover. The net-spillover soars above 400% in mid November 2008 and moves within the 400% - 500% range through February 2009. After dropping to about 200% in late February 2009, the net-spillover elevates to over 500% around mid April 2009. During this time, there are several events that turn out to have a strong influence on the variation in IYF's net-spillover. In July 2008, the failure of IndyMac Federal Bank worsens the worries about the profitability and asset quality of many financial institutions. In early September 2008, the condition of American International Group, Inc. (AIG) descends significantly. On 7 September 2008, The U.S. government takes over Fannie Mae and Freddie Mac. On 14 September 2008, Merrill Lynch is sold to Bank of America. On 15 September 2008, Lehman Brothers files for bankruptcy protection. On 3 October 2008, Wells Fargo acquires Wachovia Corp. Apparently, the series of acquisition activities keep the net-spillover at about 100% although the estimation window is rolled day by day. In November 2008, Citigroup announces that it would lay off 52,000 workers and absorb

$17 billion from its sponsored structured investment vehicles. This heightens the market anxiety. In the early part of 2009, the reports of huge losses in the last quarter of 2008 of banks and insurance companies lead to sharp drops in prices of their stocks. In June 2009, the members of the Board of Governors of the Federal Reserve System and presidents of the Federal Reserve Banks join in FOMC meetings to discuss projections for economic growth, unemployment, and inflation. According to NBER, the GFC ends in June 2009. It is apparent that the net-spillover starts its downward movement after recording the highest value in mid April 2009. Eventually, the net-spillover hits 0% benchmark in early July 2009.

Next, IYF's second tough episode lasts from mid 4th quarter 2009 to early 4th quarter 2010. During the period from late 2009 to early 2010 which coincides with the Greece Fiscal Crisis, the investors concern the default of Greece on its national debt and the domino-effect of defaults in Portugal, Ireland, Italy and Spain. The net-spillover reaches above 300% in mid November and then drops to 60% at the end of 2009. Afterwards, it moves within the 60% - 80% range during the 1st quarter 2010 and within the 20% - 50% range during the 2nd quarter 2010 before falling to the 0% benchmark in mid July 2010. As banks start making money and paying off government's funding, the investors turn positive and find the sector progressively attractive. Moreover, the reducing defaults on mortgage and consumer loan also benefit the sector. Notwithstanding, stock prices of Financials fall in the 3rd quarter 2010 due to the impact of the Financial Reform. In response, the net-spillover has another run-up starting in early August 2010. It shoots to around 100% in late August 2010 before tumbling back to 0% benchmark in mid October 2010.

Finally, IYF's last tough episode takes place during the second half of 2011. During the episode, the investors concern whether U.S. banks have exposure to possible defaults in Greece and other European nations. Moreover, disappointing news regarding

U.S. economy and housing market also put downward pressures on stocks in Financials, notably stocks of Bank of America. The net-spillover surges to 40% in early 4rd quarter 2011 and peaks at 70% in mid 4th quarter 2011. Following the static analysis, IYF has the second largest unconditional net-spillover over the full sample, say 63.1%.

3.3.1.10. Energy - IYE

Figure 5.3 provides the net-spillovers for IYE. Overall, there are seven major episodes during which IYE is a net volatility transmitter to other sectors: 2001, 2003, 2004 - 2006, 2007, 2008, 2009 - 2013, and 2014. It has been proved that volatility of IYE is largely driven by both upward and downward movements in oil prices. Also, IYE is the largest contributor of volatility to other sectors. Thus, any volatility shock to IYE caused by the variation in oil prices tends to spread over the system of sectors. It is interesting to examine how IYE's net-spillover is sensitive to events that result in oil prices fluctuations.

The first episode begins in mid May and ends in early November 2001. This episode coincides with the 2001 Recession which lasts from March to November. In 2001, both the low demand amid the recession and the high non-OPEC supply put a downward pressure on oil prices. Generally, the net-spillover stays close to 50% from mid May to September. The fact that 9/11 terrorist attacks make the investors more pessimistic about the economic outlook results in a low demand. On days the market resumes, the net-spillover surges to over 150% and keeps moving upward till the end of September. In October, the event that Enron scandal goes public heightens the investors' anxiety. On the first days of October, the net-spillover peaks at about 200%. Afterwards, the net-spillover maintains the value of above 100% till mid October before hitting the 0% benchmark in mid November.

The second episode spans from late February to late July 2003. From the 0% benchmark in late February, the net-spillover climbs to above 40% in mid March. During this time, news regarding the Iraq war makes the investors concern about the oil supply shortfall. As a result, oil prices elevate. In late April, the secure of main Iraqi oil fields reduces the risk of oil supply. Additionally, OPEC countries such as Saudi Arabia, Kuwait, and Venezuela increase their production. High oil supply then leads to a sharp decline in oil prices. The net-spillover reaches 60% in late April and 80% in early May. In June, the slower-than-expected recovery of Iraqi oil exports boosts the oil prices. In reaction, the net-spillover fluctuates around 20% through early July. After surpassing the 70% mark in late July, the net-spillover tumbles back to the 0% benchmark.

The third episode takes place from early October 2004 to 2006. Over the last quarter of 2004 and throughout 2005, oil prices record an upward movement amid the concerns about oil supply disruptions. In October 2004, oil and gas production facilities in the Gulf of Mexico are extensively damaged by hurricane Ivan. Also, the investors are more concerned about the supply stability amid several events such as Iraqi production difficulties, Iran's resumption of nuclear activities, Nigeria's production problems from social unrest, and the slowdown in Russian production growth. From the 0% benchmark, the net-spillover exceeds 100% in early January 2005. It then fluctuates between 100% and 200% for two months and goes back to 100% at the end of March 2005. The decline in IYE's net-spillover tracks the recovery in production and the new capacity added by OPEC. Next, the net-spillover soars over 550% in early June. This captures the fear of a possible oil supply disruption amid the arrival of tropical storm Arlene in the Gulf of Mexico. Afterwards, the net-spillover swings between 400% and 500% till October. Especially, the arrivals of Hurricanes Katrina in August and hurricane Rita in September send the net-spillover to high records of about 500%. The net-spillover declines after October 2005 and ends 2005 at 50%. From early 2006 to the end of July 2006, the net-spillover shows no sign of decline but fluctuating between 100% and 200%. August 2006 sees the net-spillover swing between 200% and 300%. The movement of IYE's net-spillover tracks an upward trend in oil prices that is resulted from news about the violence in the Middle East, the Prudhoe Bay oil field shutdown in Alaska, and a forecasted active hurricane. After exceeding 300% at the end of September 2006, the net-spillover falls to 0%. The last quarter of 2006 sees the net-spillover vary between 0% and 50%. IYE's net-spillover reacts to a downward trend in oil prices. Oil prices decrease because oil supply is not affected too much by anticipated factors mentioned above, oil demand drops, and increased petroleum inventories are drawn down.

The fourth episode lasts from early January to late August 2007. In January, the net-spillover varies below 50% in response to a drop in oil prices. Oil prices decline due to the low oil demand which is a result of unusually mild temperatures and the likelihood of OPEC members not implementing fully production cuts announced in late 2006. From the 0% benchmark in mid February, the net-spillover boosts to 300% in early March. It then moves between 200% and 250% before falling back to 0% in late March. Afterwards, the net-spillover rockets to 200% in early April and fluctuates between 150% and 200% through July. The net-spillover returns to the 0% benchmark in late August. The period from early September to the end of the year sees the net-spillover move within the 50% - 100% range. The movement of the net-spillover after January tracks an upward trend in oil prices. There are three main reasons that cause the increase in oil prices. First, OPEC countries, led by Saudi Arabia, further cut their oil production. Second, demand in developing countries shows a solid growth. Third, geopolitical tensions in the Middle East and the instability in Nigeria raise long-run concerns regarding supply disruption.

The fifth episode begins in late April and finishes in early November 2008. In late April, the net-spillover records an exceptional 300%. It then fluctuates within the 0% - 50% range from early May to early June. Next, it exceeds the 100% and moves between

100% and 150% during June. Afterwards, the net-spillover ends at above 50% in late June. Apparently, the net-spillover reacts to an upward movement in oil prices. Oil prices increase due to the surprisingly robust oil demand, tensions in the Middle East, the instability in Nigeria, and the decline in non-OPEC production. After mid July, the oil prices fall due to the dragged down demand amid the financial market turmoil and the sharp downturn in global economic activities. In reaction, the net-spillover has a stronger movement. From early July to mid October, the net-spillover maintains the value of above 100% before dropping to 50%. The net-spillover gives up its positive value in early November.

The sixth episode initiates in mid May 2009 and ends in mid June 2013. During this episode, the net-spillover fluctuates more frequently but not widely. Overall, the net-spillover fluctuates within the 0% - 50% range during 2009 and during the first half of 2010. In terms of 2009, the rise in oil prices over the year is majorly driven by the strengthening global activity (especially in the emerging market economies) and the effects from the cut in OPEC's oil supply. Regarding the early part of 2010, oil prices decline amid the drilling moratorium, the concern about increased regulation following the Gulf oil spill, and macroeconomic uncertainties. From the second half of 2010 to mid 2012, the net-spillover moves between 100% and 150%. Over the second half of 2010, oil prices experience an upward movement. Contributing factors to the rise include the extensive strengthening in global oil demand (notably in emerging market economies) and the depreciation of the U.S. dollar. In early 2011, concerns about the global oil supply amid the unrest in several Middle Eastern and North African countries put substantial upward pressures on oil prices. In reaction to the sharp jump in oil prices, the net-spillover surpasses 150% mark and reaches 200% in early 2011. However, oil prices move down on net over the second half of 2011. The drop is driven by the ease in the conflict in Libya and the mounting anxiety about the global growth amid the intensified European sovereign debt crisis. Concerning 2012, although oil prices go up in early 2012, they remain relatively flat over the latter part of the year. In fact, the upward pressure on prices caused by the tightening embargo on Iranian oil export is mitigated by the uncertainties about the weak global demand. During 2013, the net-spillover ranges between 0% and 100%. Over the year, oil prices decrease on net. Although the tensions in the Middle East continue to put upward pressures on oil prices, the effects are eased by the uncertainties about the oil demand in China as well as other emerging Asian countries and by the increasing oil production in North America. From 2013, U.S. starts producing more oil to mitigate the dependence on oil disruption in places such as Saudi Arabia, Iran, or Iraq. In fact, oil import has decreased as U.S. oil production continues to go upward in recent years. According to Furman (2013), the United States is now the largest producer of oil and gas in the world, passing Russia and Saudi Arabia. For the first time since 1995, the United States is producing more oil than it imports.

The final episode commences after April 2014 and lasts through the end of the examined sample. From the 0% benchmark, the net-spillover starts increasing and mounts to 500% in late May. The net-spillover then fluctuates between 400% and 500% before falling to above 200% in late June. Afterwards, the net-spillover moves within the 150% - 250% range and ends the sample at about 200%. The upward movement in IYE's net-spillover tracks the steep drop in oil prices after June. E.L (2014) suggests four main reasons for the sharp decline in oil prices. First, demand is low due to the weak economic activity, the improved efficiency, and an increased use of other fuels other than oil. Second, capacities of Iraq and Libya have not been affected by the geopolitical turmoil. Third, North America has become the world's largest oil producer. The fact that U.S. recently produces more oil than it imports results in a lot of spare supplies. Finally, the Saudis and their Gulf allies refuse to cut oil production to restore the price because this action may benefit countries they detest such as Iran and Russia.

Note that IYE has the highest unconditional net total volatility spillover of 64.7% over the sample from 2001 to 2014. S&P 500, the market index which represents the U.S. economy, is constituted by ten sectors: Consumer Discretionary, Consumer Staples, Energy, Financials, Healthcare, Industrials, Information Technology, Materials, Telecommunications, and Utilities. The interaction of the sectors between themselves is approximately equivalent to the interaction of the sectors with the market index. In terms of volatility spillover, if a sector dominates all the other sectors, this sector mainly contributes to the market index which is the aggregation of all the sectors. It is empirically shown that Energy contributes the most to volatility of other sectors by having a large and consistent magnitude of volatility spillover over time. Moreover, Energy is majorly driven by fluctuations in oil prices. This eventually implies that oil prices have an impact on volatility of other sectors as well as the market index as a whole.

3.3.2. Net Total Directional Volatility Spillover during the 2001 Recession and the GFC

This part screens on how systematic volatilities during the 2001 Recession and the GFC are explained by volatility shocks from the associated sectors.

In terms of the 2001 Recession, IYW is the most crucial sector of the net-spillover, followed by IYZ and IYE. The net-spillover of IYW stays at about 200% in the first two quarters and at about 100% in the last two months of the recession. Several days after the start of the recession, IYZ's net-spillover turns positive and fluctuates around 200% till the end of the recession. The net-spillover of IYE is positive from mid 2nd quarter 2001 to early November 2001. Most of the time, IYE's net-spillover swings around 50%. Especially, the net-spillover of IYE exceeds 100% in early September and reaches as high as 200% in early October.

Regarding the GFC, IYF is the largest net volatility transmitter. Besides, IYM, IYE, and IDU also have episodes of significant net-spillover. Apart from the other three sectors, IYF sees positive net-spillover all the time throughout the crisis. From the start of the crisis to early 1st quarter 2008, the net-spillover of IYF is as high as 150%. The net-spillover then keeps its value close to 400% through late 2nd quarter 2008. After that, the net-spillover goes through mid 4th quarter 2008 with the value of about 100%. Afterwards, the net-spillover surges back to 400% in the second half of the 4th quarter 2008 and fluctuates around there for a while before dropping to 250% in mid 1st quarter 2009. The decline is followed by a sharp jump up to 500% in early 2nd quarter 2009 and a downward movement through the end of the crisis. Regarding IYM, the sector has three main episodes taking the role as a net volatility transmitter. The first episode takes place between the start of the crisis and mid 2nd quarter 2008. The net-spillover fluctuates around 200%, 50%, and 300% in the early, middle, and latter parts of the first episode, respectively. The second episode lasts from late 2nd quarter 2008 to mid 4th quarter 2008. During this episode, the net-spillover fluctuates around 100%. The last episode lasts from mid 1st quarter 2009 to the end of the crisis. The net-spillover starts at around 50% in the early part of the episode. It then fluctuates around 100% during the middle part of the episode and mounts to 200% in the latter part of the episode. In terms of IYE, there are three key episodes of significant positive net-spillover. The first episode lasts from the start of the crisis to early 1st quarter 2008. During this episode, the net-spillover fluctuates around 70%. Next, the second episode takes place from early 2nd quarter 2008 to mid 4th quarter 2008. The average net-spillover over this episode is about 110%. Furthermore, the last episode spans from early 2nd quarter 2009 to the end of the crisis. This episode involves the net-spillover movement around 50%. Regarding IDU, the sector has only one significant episode taking the role as a net volatility transmitter. The episode lasts from early 2^{nd} quarter 2009 to the end of the crisis, and the net-spillover fluctuates around 50% during the episode.

In summary, Energy and Basic Materials are the two largest net volatility transmitters among the sectors. Whereas, Consumer Goods, Consumer Services, and Healthcare are the top three largest net volatility receivers among the ten sectors. It is apparent that Energy is the only sector which contributes largely to volatility of other sectors during the 2001 Recession and the GFC. Besides, Basic Materials has the substantial volatility transmission to other sectors during and after the GFC. While Technology and Telecommunications account the most for volatility of other sectors during the 2001 Recession, Financials is largely responsible for volatility of other sectors during the GFC.

3.4. Rolling Net Pairwise Directional Volatility Spillover

[Insert Figure 6 around here]

While the net total directional volatility spillover suggests whether a given sector is a net transmitter/receiver of volatility to/from the other nine sectors (a one-to-nine relation), the net pairwise directional volatility spillover indicates whether a given sector is a net transmitter/receiver of volatility to/from each of the other nine sectors (a one-to-one relation). By looking at each of the 45 distinct sector pairs over the 2001 Recession and the GFC, volatility transmission between U.S. sectors during highly volatile times are more apparent in net pairwise terms. Note that saying sector A is a net volatility transmitter to sector B is equivalent to saying sector B is a net volatility receiver from sector A, and vice versa.

3.4.1. The 2001 Recession

This section discusses the rolling net pairwise spillovers for 45 distinct sector pairs during the 2001 Recession.

First, there are 22 sector pairs in each of which one sector tends to dominate the other sector consistently over the recession. Starting with IYW, the sector is a net volatility transmitter in each of these sector pairs: IDU – IYW (Figure 6.8), IYC – IYW (Figure 6.16), IYF – IYW (Figure 6.29), IYH – IYW (Figure 6.34), IYJ – IYW (Figure 6.38), IYK – IYW (Figure 6.41), and IYM – IYW (Figure 6.43). In terms of IYZ, the sector is a net volatility transmitter in each of these sector pairs: IDU – IYZ (Figure 6.9), IYC – IYZ (Figure 6.17), IYF – IYZ (Figure 6.30), IYH – IYZ (Figure 6.35), IYJ – IYZ (Figure 6.39), IYK – IYZ (Figure 6.42), and IYM – IYZ (Figure 6.44). Next, IYE is also a net volatility transmitter in each of these sector pairs: IDU – IYE (Figure 6.2), IYC – IYE (Figure 6.10), IYE – IYH (Figure 6.19), and IYE – IYK (Figure 6.21). On the contrary, IYK is a net volatility receiver in each of these sector pairs: IYC – IYK (Figure 6.14), IYF – IYK (Figure 6.27), and IYK – IYM (Figure 6.40). Furthermore, while IDU is a net volatility receiver in several sector pairs discussed above, the sector is a net volatility transmitter in IDU – IYH (Figure 6.4).

Second, there are 3 sector pairs in each of which one sector tends to dominate the other sector but inconsistently over the recession. Beginning with IDU - IYK (Figure 6.6), IDU transmits volatility to IYK over two main episodes: during March and from late 3rd quarter to the end of the recession. Regarding IYE - IYF (Figure 6.18), IYF receives volatility from IYE over two major episodes: from mid 2nd quarter to late 2nd quarter and from late 3rd quarter to mid 4th quarter. In terms of IYE - IYM (Figure 6.22), IYE is a net volatility transmitter to IYM over the episode from mid 2nd quarter to mid 4th quarter.

Lastly, there are 20 sector pairs in each of which the two sectors tend to exchange the roles in volatility transmission for each other over the recession. They are IDU – IYC (Figure 6.1), IDU – IYF (Figure 6.3), IDU - IYJ (Figure 6.5), IDU - IYM (Figure 6.7), IYC - IYF (Figure 6.11), IYC - IYH (Figure 6.12), IYC - IYJ (Figure 6.13), IYC – IYM (Figure 6.15), IYE - IYJ (Figure 6.20), IYE – IYW (Figure 6.23), IYE - IYZ (Figure 6.24), IYF - IYH (Figure 6.25), IYF - IYJ (Figure 6.26), IYF – IYM (Figure 6.28), IYH - IYJ (Figure 6.31), IYH - IYK (Figure 6.32), IYH - IYM (Figure 6.33), IYJ - IYK (Figure 6.36), IYJ - IYM (Figure 6.37), and IYW - IYZ (Figure 6.45).

As discussed in section 3.3.2, Technology, Telecommunications, and Energy are particular sectors which contribute largely to volatility of other sectors (in total terms) during the 2001 Recession. It is interesting to summarize their volatility spillovers in net pairwise terms. In terms of Technology, over the recession, the sector consistently dominates all other sectors except Telecommunications and Energy. In relation with Telecommunications or Energy, the sector sees the variation in its role in volatility transmission over the recession. Regarding Telecommunications, over the recession, the sector consistently dominates other sectors excluding Technology and Energy. In relation with Technology or Energy, the sector's role in volatility transmission varies over the recession. In the case of Energy, over the recession, the sector is a consistent volatility transmitter to all other sectors but Financials, Materials, Industrials, Technology, and Telecommunication. In relation with Financials or Basic Materials, Energy dominates each of these two sectors but not consistently over the recession. In other words, there are episodes during which Energy and Financials or Energy and Basic Materials are almost neutral in volatility transmission. In relation with Industrials, Technology, or Telecommunications, the role of Energy in volatility transmission changes over the recession.

3.4.2. The GFC

This section discusses the rolling net pairwise spillovers for 45 distinct sector pairs during the GFC.

First, there are 27 sector pairs in each of which one sector tends to dominate the other sector consistently over the crisis. Starting with IYF, the sector is a net volatility transmitter in each of these sector pairs: IDU – IYF (Figure 6.3), IYC – IYF (Figure 6.11), IYF – IYH (Figure 6.25), IYF – IYJ (Figure 6.26), IYF – IYK (Figure 6.27), IYF – IYW (Figure 6.29), and IYF – IYZ (Figure 6.30). In terms of IYE, the sector is a net volatility transmitter in each of these sector pairs: IDU – IYE (Figure 6.2), IYC – IYE (Figure 6.10), IYE – IYH (Figure 6.19), IYE – IYK (Figure 6.21), and IYE – IYZ (Figure 6.24). Next, IYM is also a net volatility transmitter in each of these sector pairs: IDU – IYM (Figure 6.7), IYC – IYM (Figure 6.15), IYH – IYM (Figure 6.33), IYJ – IYM (Figure 6.37), IYK – IYM (Figure 6.40), IYM – IYW (Figure 6.43), and IYM – IYZ (Figure 6.44). On the contrary, IYK is a net volatility receiver in each of these sector pairs: IYC – IYK (Figure

6.14), IYJ – IYK (Figure 6.36), IYK – IYW (Figure 6.41), and IYK – IYZ (Figure 6.42). Besides, IYH is also a net volatility receiver in each of these sector pairs: IYC – IYH (Figure 6.12), IYH – IYJ (Figure 6.31), IYH – IYW (Figure 6.34), and IYH – IYZ (Figure 6.35).

Second, there are 7 sector pairs in each of which one sector tends to dominate the other sector but inconsistently over the crisis. Beginning with IDU - IYH (Figure 6.4), IDU transmits volatility to IYH over two main episodes: from early 2nd quarter 2008 to late 1st quarter 2009 and from early 2nd quarter 2009 to the end of the crisis. Regarding IDU - IYK (Figure 6.6), IYK receives volatility from IDU over two major episodes: from late 2nd quarter 2008 to mid 4th quarter 2008 and from early 1st quarter 2009 to the end of the crisis. Regarding the IYE - IYF (Figure 6.18), IYF is a net volatility transmitter to IYE over two key episodes: from early 1st quarter 2008 to late 2nd quarter 2008 and from early 4th quarter 2008 to the end of the crisis. In terms of IYE - IYJ (Figure 6.20), IYJ is a net volatility receiver from IYE over three main episodes: from late 2007 to early 1st quarter 2008, from late 2nd quarter 2008 to mid 4th quarter 2008, and from early 2nd quarter 2009 to the end of the crisis. In respect to IYE - IYW (Figure 6.23), IYE has two substantial episodes during which it contributes to volatility of IYW: from late 2007 to early 1st quarter 2008 and from late 2nd quarter 2008 to the end of the crisis. Concerning IYF - IYM (Figure 6.28), IYF experiences two major episodes during which its spillover to IYM is larger than that in the reverse direction: from early 1st quarter 2008 to late 2nd quarter 2008 and from mid 4th quarter 2008 to early 2nd quarter 2009. In terms of IYJ - IYZ (Figure 6.39), IYJ transmits volatility to IYZ over the episode from early 2nd quarter 2008 to the end of the crisis.

Lastly, there are 11 sector pairs in each of which the two sectors tend to exchange the roles in volatility transmission for each other over the crisis. They are IDU - IYC (Figure 6.1), IDU - IYJ (Figure 6.5), IDU – IYW (Figure 6.8), IDU - IYZ (Figure 6.9), IYC - IYJ (Figure 6.13), IYC - IYW (Figure 6.16), IYC - IYW (Figure 6.17), IYE - IYM (Figure 6.22), IYH - IYK (Figure 6.32), IYJ - IYW (Figure 6.38), and IYW – IYZ (Figure 6.45).

As discussed in section 3.3.2, Financials, Basic Materials, and Energy are notable sectors which contribute largely to volatility of other sectors (in total terms) during the GFC. In terms of Energy, throughout the crisis, it dominates each the other sectors except Financials and Basic Materials. In relation with Financials, Energy and Financials are almost neutral in volatility transmission around the height of the crisis. In other words, the two sectors impact each other equally, and their net pairwise directional volatility spillover is balanced to approximately 0%. Moreover, Financials transmits volatility to Energy during two episodes: from early 1st quarter 2008 to late 2nd quarter 2008 and from early 4th quarter 2008 to the end of the crisis. In relation with Basic Materials, the impact of Basic Materials on Energy is larger than that in the reverse direction from late 2nd quarter 2008 to late 3rd quarter 2008. However, Energy transmits volatility to Basic Materials in the early part and in the latter part of the crisis at a relatively large magnitude of spillover. Regarding Financials, throughout the crisis, the sector dominates each of the other sectors except Energy and Basic Materials. In relation with Basic Materials, Financials and Basic Materials are almost neutral in volatility transmission around the 3rd quarter 2008. However, Financials transmits volatility to Basic Materials in episodes other than the 3rd quarter 2008 at a relatively large magnitude of spillover. In the case of Basic Materials, throughout the crisis, the sector dominates each of the other sectors except Energy and Financials.

In summary, through the focus on the 2001 Recession and the GFC, volatility transmission between sectors during the most turbulent times over the examined sample are more apparent in net pairwise terms.

V. CONCLUSIONS

As sector ETFs provide the exposure on sector indexes, the variation in prices of sector ETFs indicates the sentiment of investors towards the U.S. sectors. Assume that the tracking errors are negligible over time, volatility of sector ETFs reflects volatility of the respective indexes. The objective of this paper is simple. In the assumption that the ten U.S. sectors are connected over time, this paper investigates volatility transmission between ten iShares sector ETFs in both static and dynamic senses. This paper uses high frequency data ranging from 2 January 2001 to 31 December 2014 and employs Diebold-Yilmaz Connectedness framework.

Overall, there are three main findings. First, the ten sectors have become more connected since late 2006. Second, Energy and Basic Materials are the two largest net volatility transmitters while Consumer Goods, Consumer Services, and Healthcare are the top three largest net volatility receivers among the ten sectors. Third, volatility transmission between sectors varies during the 2001 Recession and the GFC. Energy is the only sector which contributes largely to volatility of other sectors during the 2001 Recession and the GFC. Besides, Basic Materials has the substantial volatility transmission to other sectors during and after the GFC. While Technology and Telecommunications account the most for volatility of other sectors during the 2001 Recession, Financials is largely responsible for volatility of other sectors during the GFC. These findings suggest two main implications. First, the investors should consider the spillover effects when making decisions on their investments (especially during highly turbulent times) as news and shocks that impact a certain sector will ultimately spread over all other sectors through the high connectedness. Second, findings also imply the impact of oil prices on the market index which is the aggregation of all the sectors.

This paper has both practical and academic contributions. In terms of practical contributions, findings are useful for the investors and the policy makers. The investors tend to choose defensive sectors (i.e. Consumer Goods, Healthcare, and Utilities) in market downturns without considering the spillover effects. As volatility from one sector tends to spread over other sectors via spillovers, a good understanding of volatility transmission between sectors supports the investors in making decisions on sector rotations. Moreover, the determination of cycles, bursts, and trends in volatility transmission between sectors over time assists the policy makers in addressing financial stability issues and problems related to contagion between sectors. Regarding academic contribution, this paper applies Diebold-Yilmaz Connectedness framework in the volatility spillover measurement at sectoral level for the first time, providing reference for further studies. Also, this paper contributes to the literature by providing new empirical findings about volatility transmission at sectoral level. This paper has two shortcomings which can be considered areas for further studies. First, this paper is apart from investigating the asymmetry of volatility transmission between sectors. Second, the detection of herding behavior between sectors should be also investigated.

VI. REFERENCES

Andersen, T. G., Bollerslev T., Diebold, F. X., & Ebens, H. (2001). The distribution of realized stock return volatility. *Journal of Financial Econometrics, 61*(1), 43-76.

Andersen, T. G., Bollerslev T., Diebold, F. X., & Labys, P. (2003). Modeling and Forecasting Realized Volatility. *Journal of the Econometric Society, 71*(2), 579-625.

Arouri, M., Jouini, J., & Nguyen, D. K. (2011). Volatility Spillovers between Oil Prices and Stock Sector Returns: Implications for Portfolio Management. *Journal of International Money and Finance, 30*(7), 1387-1405.

Balli, H. O., Balli, F., & Louis, R. J. (2013). Time-Varying Spillover Effects on Sectoral Equity Returns. *International Review of Finance, 12*(1), 67-91.

Barunik, J., Kocenda, E., & Vacha, L. (2015, April). *Asymmetric Connectedness on the U.S. Stock Market: Bad and Good Volatility Spillovers* (No. 5305). CISIFO Working Paper. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2603131

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

Burns, W. J., Peters, E., & Slovic, P. (2012). Risk perception and the economic crisis: A longitudinal study of the trajectory of perceived risk. *Risk Analysis: an Intenational Journal. 32*(4), 659-677.

Calmes, J. (2012). *Demystifying the Fiscal Impasse That Is Vexing Washington*. Retrieved from http://www.nytimes.com/2012/11/16/us/politics/the-fiscal-cliff-explained.html?_r=0

Davidson, P. (2014). *Fed policymakers cut growth forecast*. Retrieved from http://www.usatoday.com/story/money/business/2014/06/18/federal-reserve-june-meeting/10743961/

Davig, T., & Foerster, A. (2014, April). *Uncertainty and fiscal cliffs* (No. RWP 14-04). The Federal Reserve Bank of Kansas City Working Paper. Retrieved from https://ideas.repec.org/p/fip/fedkrw/rwp14-04.html

Dickey, D. A., & Fuller, W. A. (1981). Likelihood Ratio Statistics for Autoregressive Time- Series with a Unit Root. *Econometrica, 49*(4), 1057-72.

Diebold, F. X., & Yilmaz, K. (2009a). Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets. *Economic Journal, Royal Economic Society, 119*(534), 158-171.

Diebold, F. X., & Yilmaz, K. (2009b). Equity Market Spillovers in the Americas. *Journal Economia Chilena (The Chilean Economy), 12*(2), 55-65.

Diebold, F. X., & Yilmaz, K. (2010). Better to give than to receive: Predictive directional measurement of volatility spillovers. *International Journal of Forecasting, 28*(1), 57-66.

Diebold, F. X., & Yilmaz, K. (2011). On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms. *Journal of Econometrics, 182*(1), 119-134.

Diebold, F. X., & Yilmaz, K. (2013a). *Measuring the Volatility Connectedness of Bankson Both Sides of the Atlantic*. Unpublished manuscript. University of Pennsylvania and Koc University. Retrieved from www.eea-esem.com/files/papers/eea-esem/2013/2566/EuUSbanks.pdf

Diebold, F. X., & Yilmaz, K. (2013b, December). *Measuring the Dynamics of Global Business Cycle Connectedness* (No. 13-070). PIER Working Paper. Retrieved from https://ideas.repec.org/p/pen/papers/13-070.html

Diebold, F. X., & Yilmaz, K. (2014). *Trans-atlantic volatility connectedness among financial institutions*. Unpublished manuscript. University of Pennsylvania and Koc University. Retrieved from http://www.ssc.upenn.edu/~fdiebold/papers/paper120/euusbanks.pdf

E.L (2014). *Why the oil price is falling*. Retrieved from http://www.economist.com/blogs/economist-explains/2014/12/economist-explains-4

Engle, R. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of united kingdom inflation. *Econometrica, 50*(4), 987-1007.

Engle, R. F., & Kroner, K. F. (1995). Multivariate Simultaneous Generalized ARCH. *Econometric Theory, 11*(1), 122-150.

Ewing, B. T. (2002). The transmission of shocks among S&P indexes. *Applied Financial Economics, 12*(4), 285–290.

Furman, J. (2013). *The Economy in 2013*. Retrieved from https://www.whitehouse.gov/blog/2013/12/19/economy-2013

Global Economic Prospects (2015). *Understanding the Plunge in Oil Prices: Sources and Implications.* Retrieved from http://www.worldbank.org/content/dam/Worldbank/GEP/GEP2015a/pdfs/GEP2015a_chapter4_report_oil.pdf

Granger, C. W. J. (1969). Investigating Causal Relations by Econometric Models and Crose Spectral Methods. *Econometrica*, *37*(3), 424-38.

Hacker, R. S., & Hatemi-J, A. (2006). Tests for causality between integrated variables using asymptotic and bootstrap distributions: theory and application. *Applied Economics, 38*(13), 1489-1500.

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

Hassan, S. A., & Malik, F. (2007). Multivariate GARCH modeling of sector volatility Transmission. *Quarterly Review of Economics and Finance, 47*(3), 470-480.

Koop, G., Pesaran, M. H., & Potter, S. M. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics, 74*(1), 119-147.

Lee, B. J., Jang, C. W., & Huang, B. N. (2012). Oil price movements and stock markets revisited: A case of sector stock price indexes in the G-7 countries. *Energy Economics, 34*(5), 1284-1300.

Lee, K. H., Elkassabgi A., & Hsieh, W. J. (2014). Volatility of the Utilities Industry: Its Causal Relationship to Other Nine Industries. *Review of Economics & Finance, 4*(5), 15-22.

Lelis, N., & Pirhadi, L. (2011). *Oil Volatility Spillovers to the US and EU Industries* (Master's Essay II). School of Economics and Management Lund University, Lund, Sweetden.

Malik, F., & Ewing, B. T. (2009). Volatility Transmission between Oil Prices and Equity Sector Returns. *International Review of Financial Analysis, 18*(3), 95-100.

McGranahan, L., & Nohel, T. (2014). *The Fiscal Cliff and the Dynamics of Income*. Retrieved from https://ideas.repec.org/a/fip/fedhle/00006.html

Nandha, M., & Faff, R. (2008). Does oil move equity prices?. *Journal of Energy Economics, A global view, 30*(3), 986-997.

Pelletier, D. (1996). Regime switching for dynamic correlations. *Journal of Econometrics, 131*(1-2), 445-473.

Pesaran, M. H., & Shin, Y. (1998). Generalized Impulse Response Analysis in Linear Multivariate Models. *Economics Letters, 58*(1), 17-29.

Popper, N. (2013). *How a Debt Ceiling Crisis Could Do More Harm Than the Shutdown*. Retrieved from http://www.nytimes.com/2013/10/04/us/politics/how-debt-ceiling-could-do-more-harm-than-the-impasse-in-congress.html?_r=0

Ross, S. A. (1989). Information and volatility: The no-arbitrage martingale property to timing and resolution irrelevancy. *Journal of Finance, 44*(1), 1-17.

Siddiqui, S. (2013). *Report on Macroeconomic Effect of Debt Ceiling Brinkmanship*. Retrieved from http://www.treasury.gov/connect/blog/Pages/Report-on-Macroeconomic-Effect-of-Debt-Ceiling-Brinkmanship.aspx

Straetmans, S., Verschoor, W., & Wolff, C. (2008). Extreme U.S. stock market fluctuations in the wake of 9/11. *Journal of Applied Econometrics, 23*(1), 17-42.

Taylor, S. J. (1982). Financial returns modelled by the product of two stochastic processes a study of daily sugar prices 1961-79. In O. D. Anderson (Eds.), *Time Series Analysis: Theory and Practice 1* (pp. 203-226). Amsterdam: North-Holland.

Taylor, S. J. (1994). Modelling stochastic volatility: a review and comparative study. *Mathematical Finance, 4*(2), 183-204.

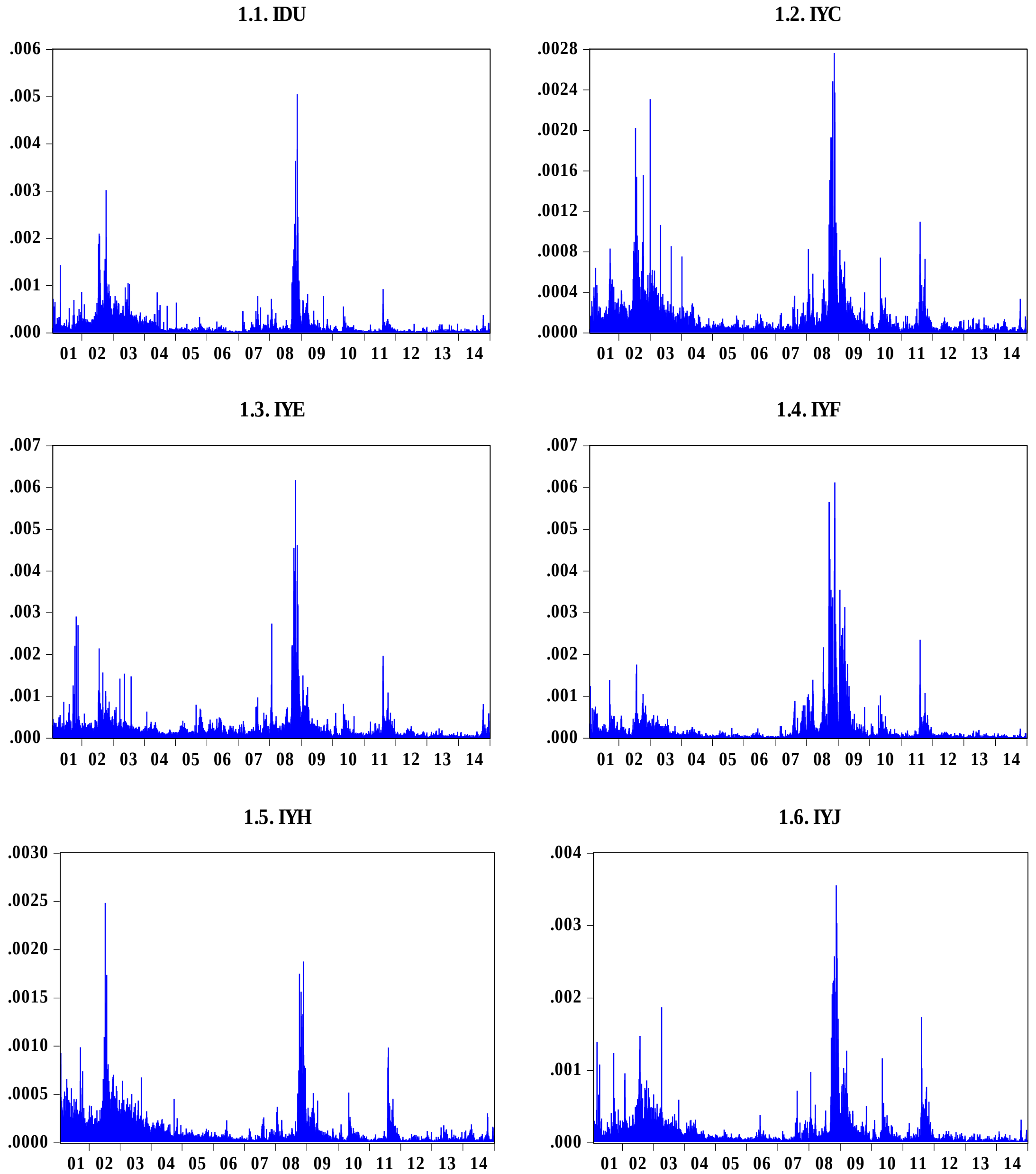
Zhou, X., Zhang, W., & Zhang, J. (2012). Volatility spillovers between the Chinese and world equity markets. *Pacific-Basin Finance Journal, 20*(2), 247-270.

VII. APPENDIX

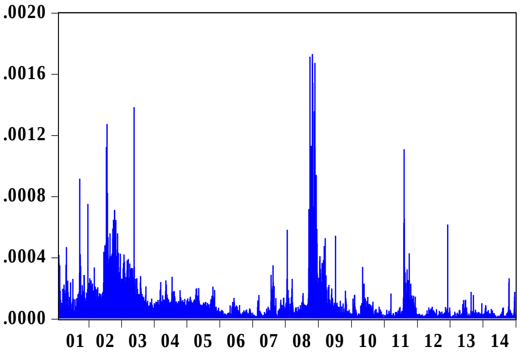
1. FIGURES

Figure 1. Daily U.S. Sector ETFs Volatility

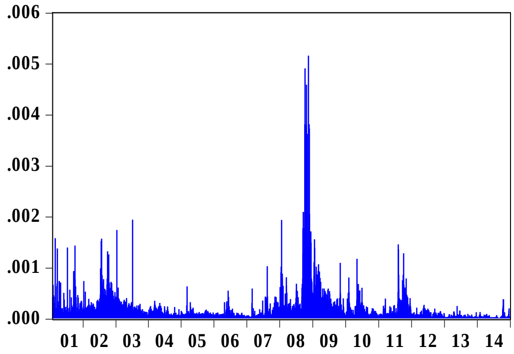
Note: The sample spans from 2 January 2001 to 31 December 2014 and has 3,498 observations.



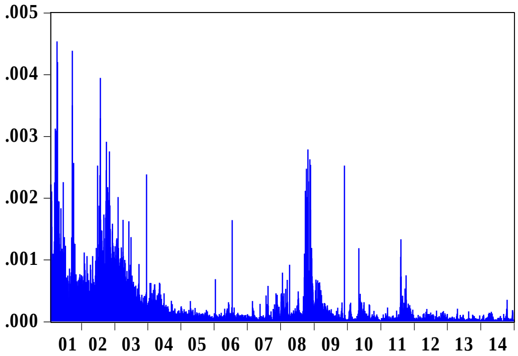
1.7. IYK



1.8. IYM



1.9. IYW



1.10. IYZ

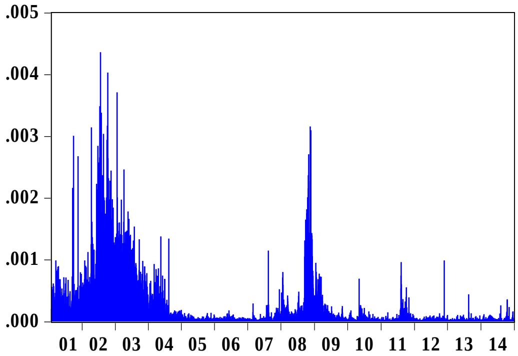
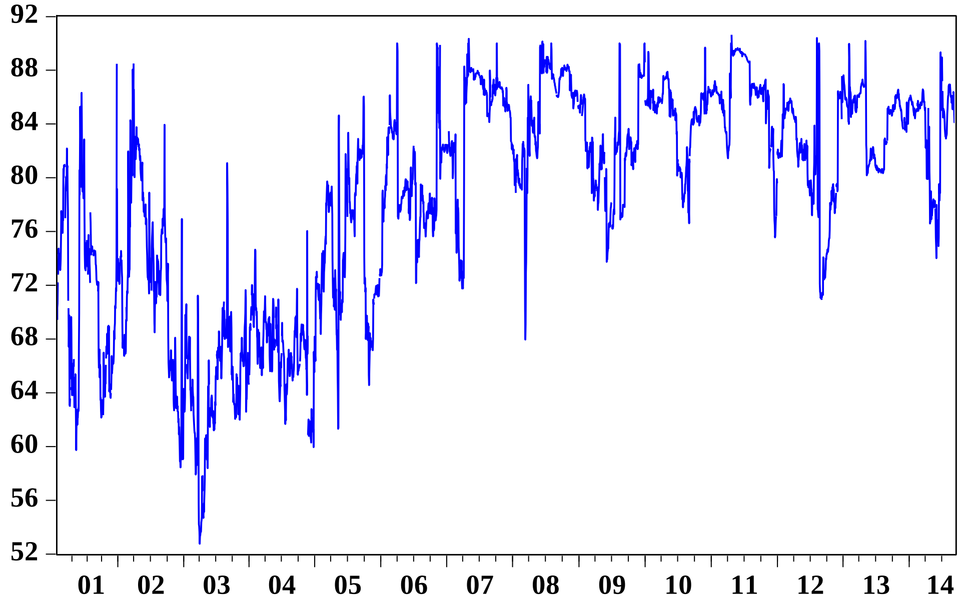
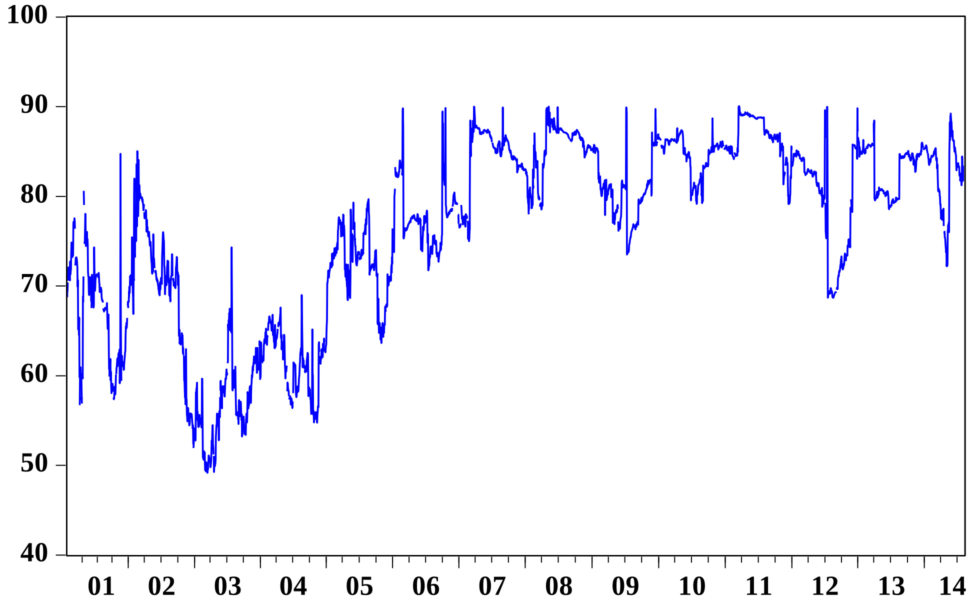


Figure 2. Total Volatility Spillover

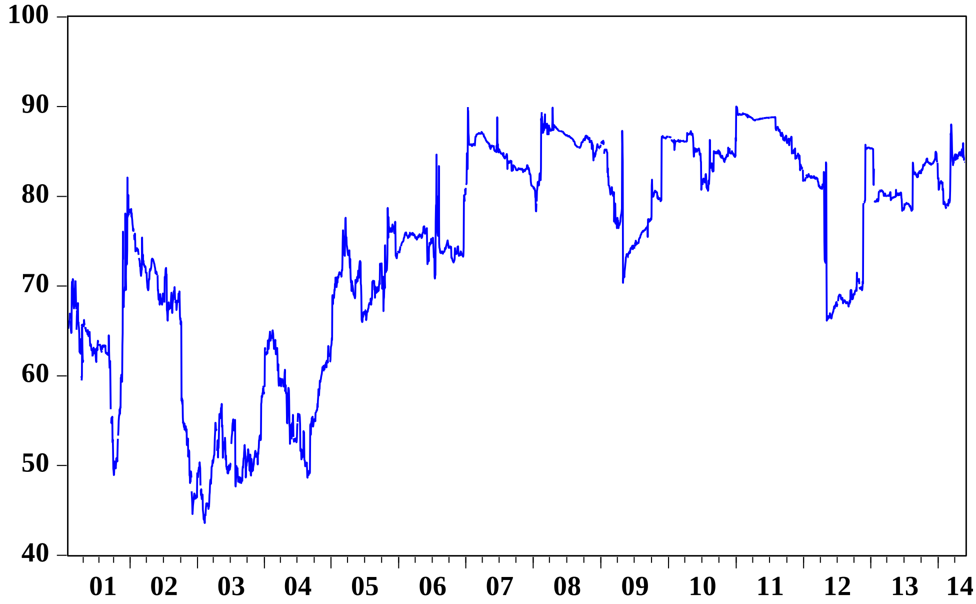
2.1. P = 3, H = 12, W = 75



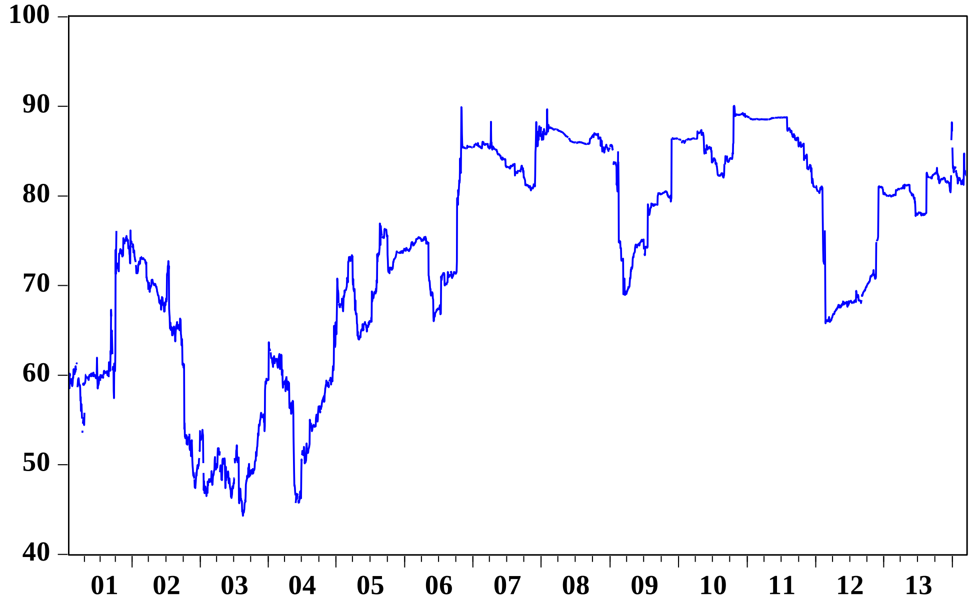
2.2. P = 3, H = 12, W = 100



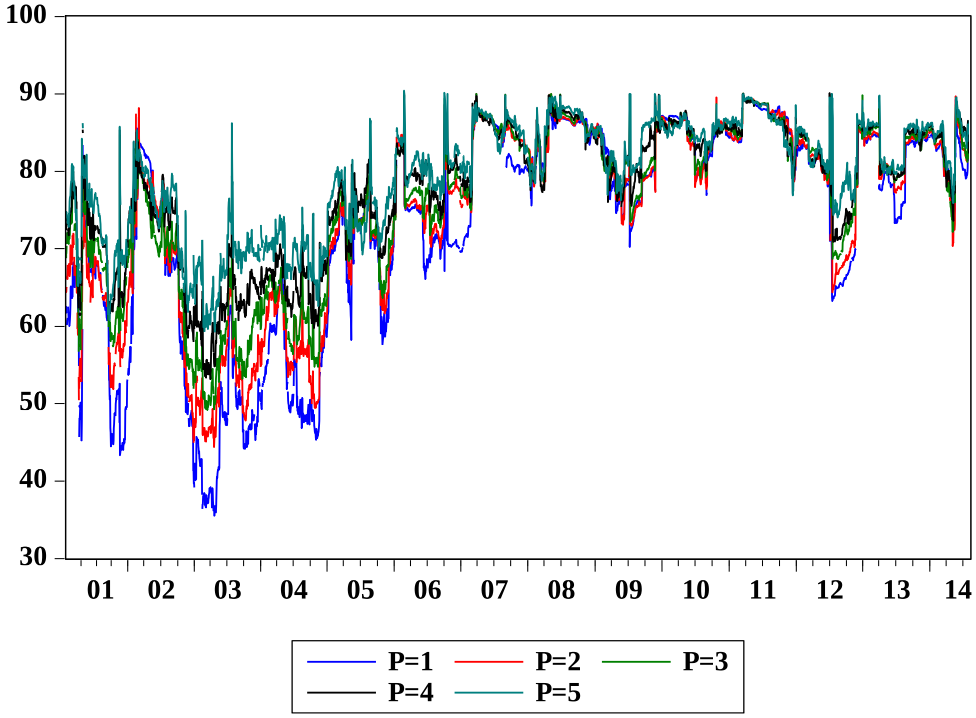
2.3. P = 3, H = 12, W = 150



2.4. P = 3, H = 12, W = 200



2.5. H = 12, W = 100


100
90
80
70
60
50
40
30
01 02 03 04 05 06 07 08 09 10 11 12 13 14
P=1
P=2
P=3
P=4
P=5

2.6. P = 3, W = 100

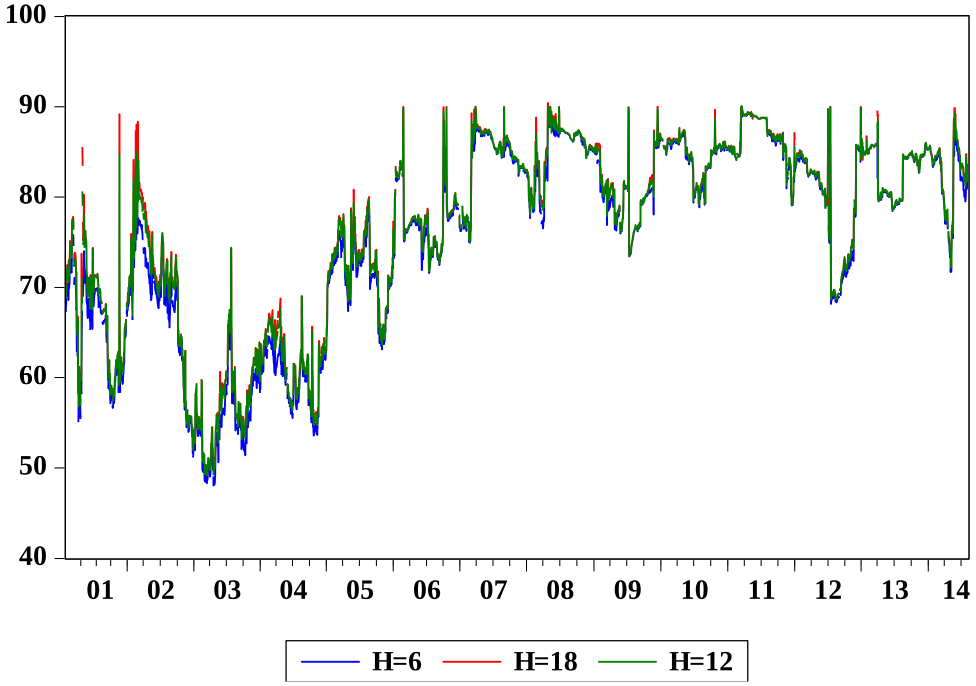
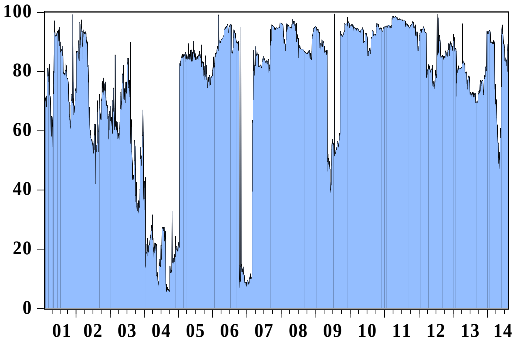

100
90
80
70
60
50
40
01 02 03 04 05 06 07 08 09 10 11 12 13 14
H=6
H=18
H=12

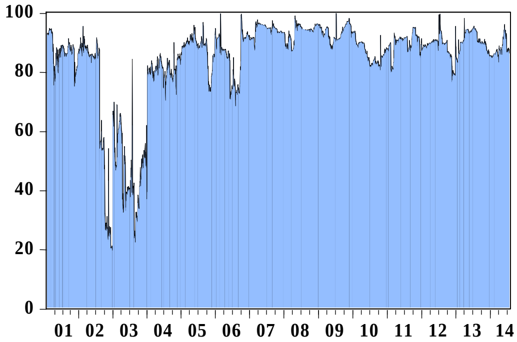
Figure 3. Total Directional Volatility Spillover from the Others to Each of Ten Sectors

Note: P = 3 lags, H = 12 days, and W = 100 days.

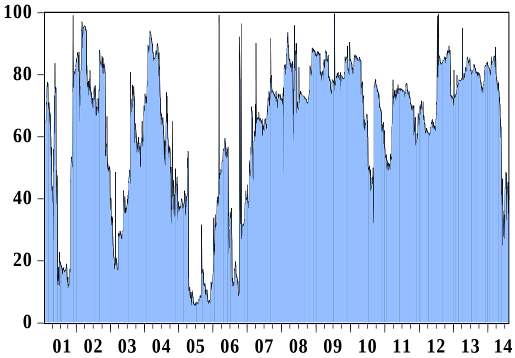
3.1. IDU



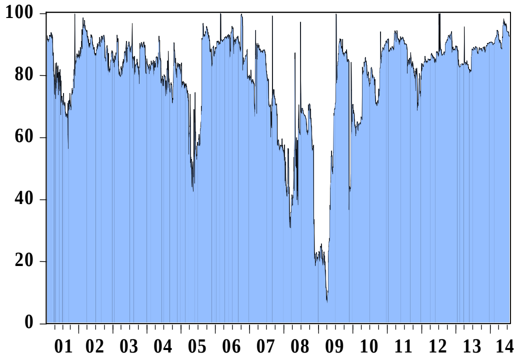
3.2. IYC



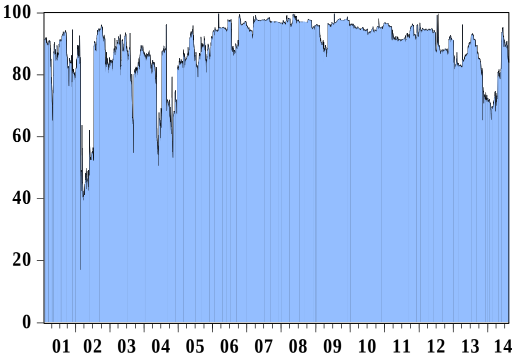
3.3. IYE



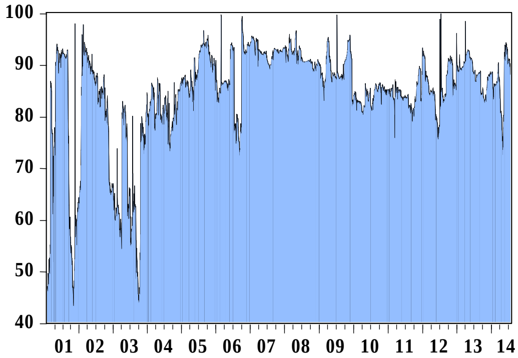
3.4. IYF



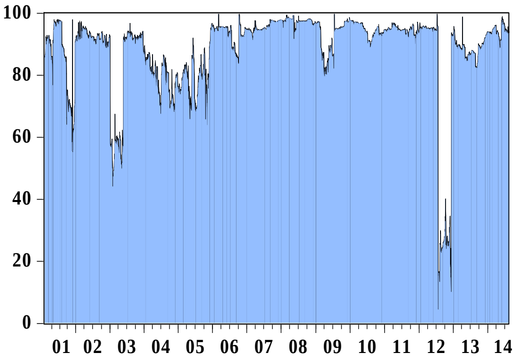
3.5. IYH



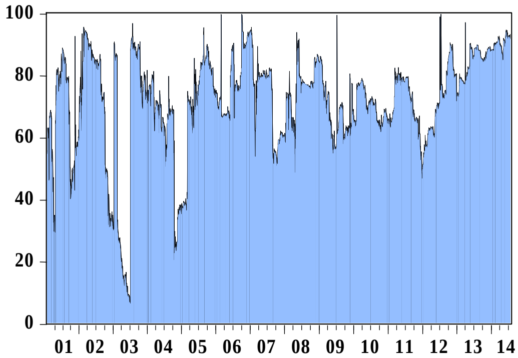
3.6. IYJ



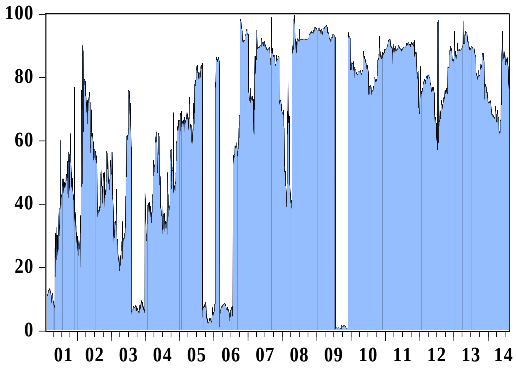
3.7. IYK



3.8. IYM



3.9. IYW



3.10. IYZ

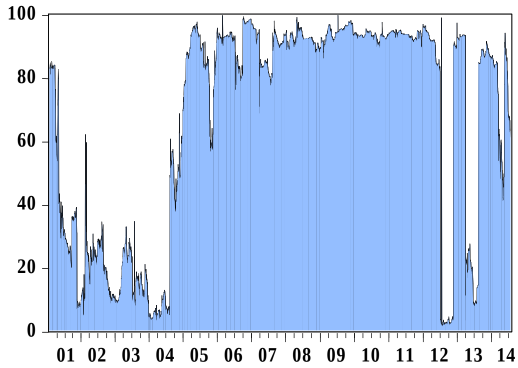
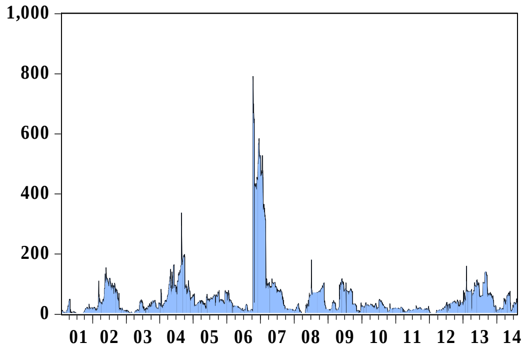


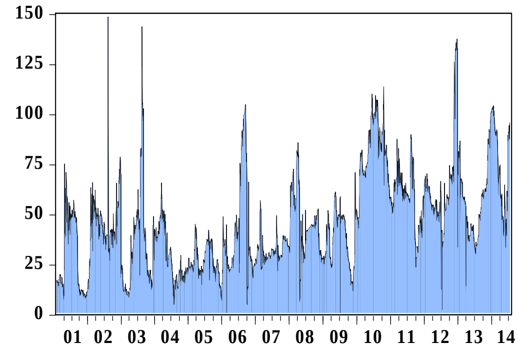
Figure 4. Total Directional Volatility Spillover to the Others from Each of Ten Sectors

Note: P = 3 lags, H = 12 days, and W = 100 days.

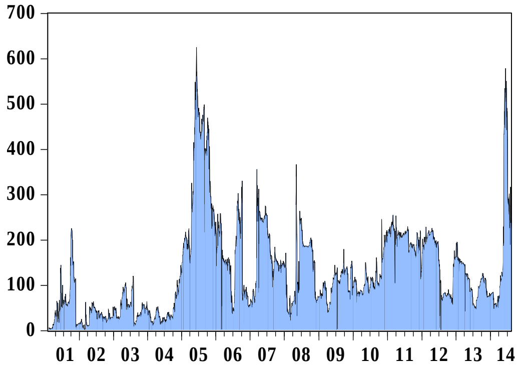
4.1. IDU



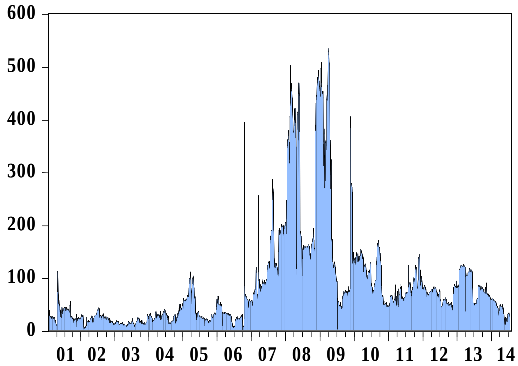
4.2. IYC



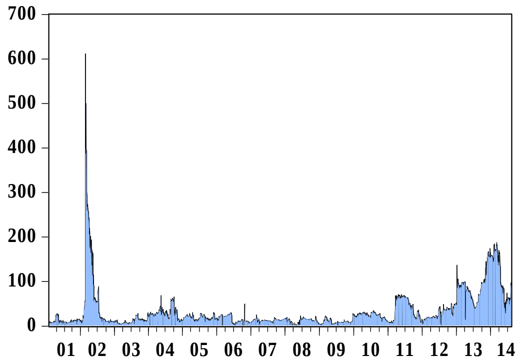
4.3. IYE



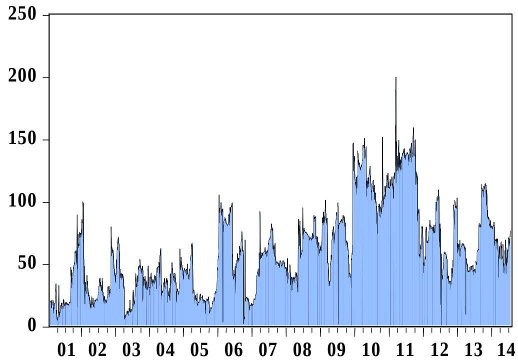
4.4. IYF



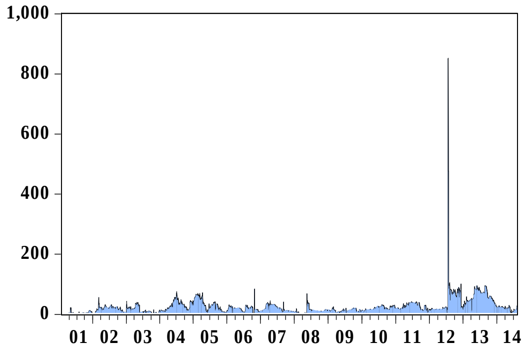
4.5. IYH



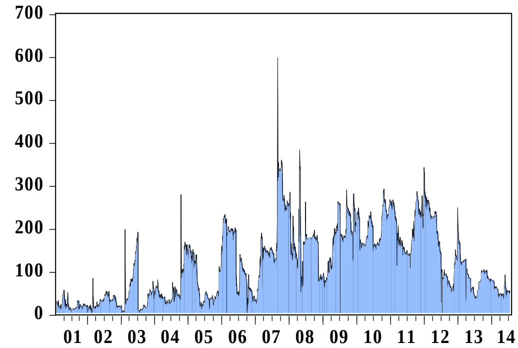
4.6. IYJ



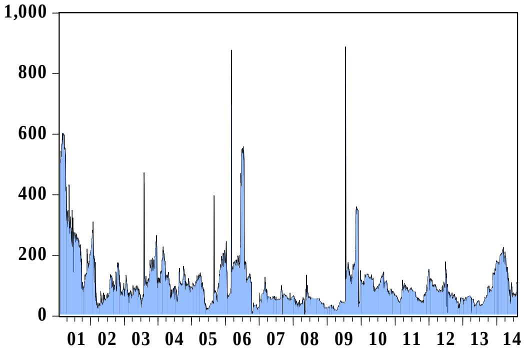
4.7. IYK



4.8. IYM



4.9. IYW



4.10. IYZ

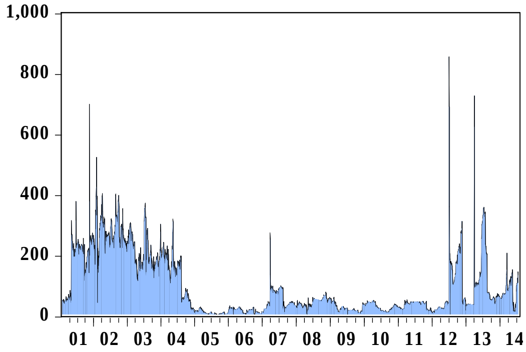
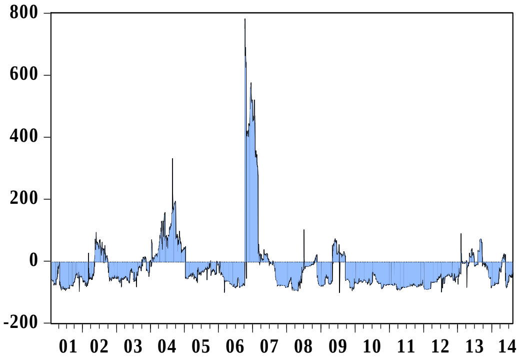


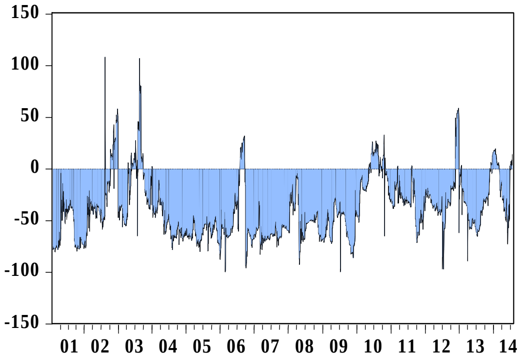
Figure 5. Net Total Directional Volatility Spillover

Note: P = 3 lags, H = 12 days, and W = 100 days.

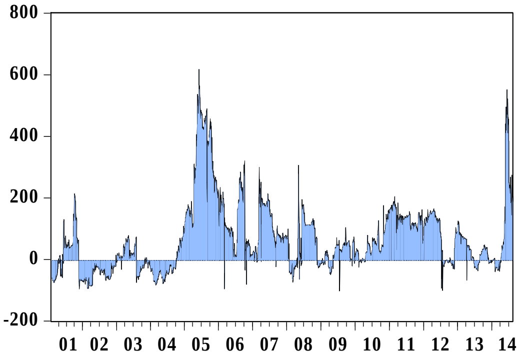
5.1. IDU



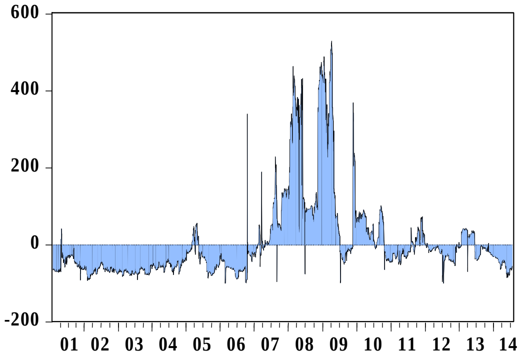
5.2. IYC



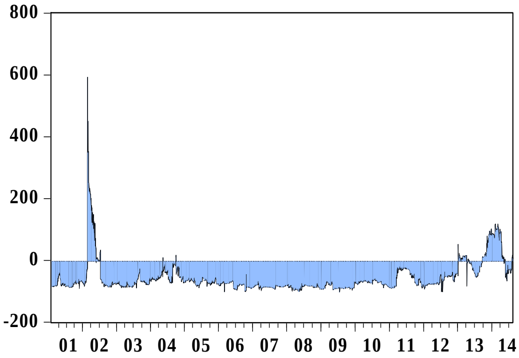
5.3. IYE



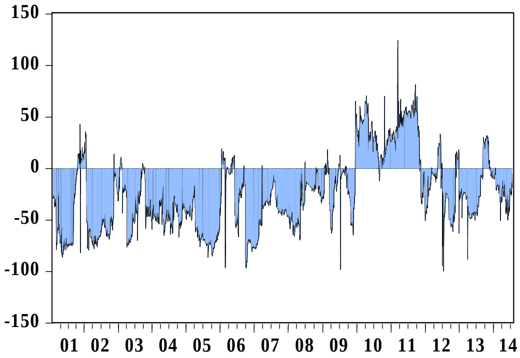
5.4. IYF



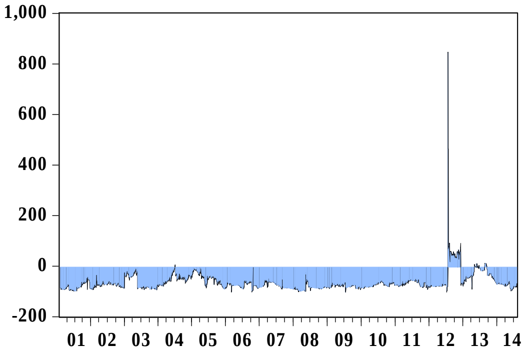
5.5. IYH



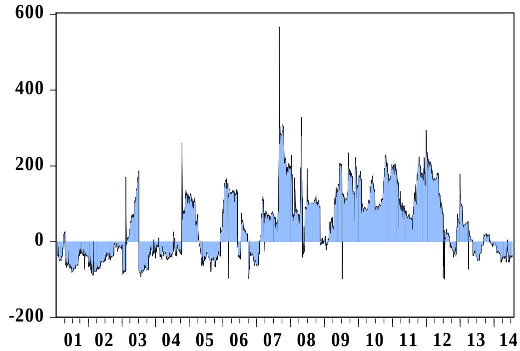
5.6. IYJ



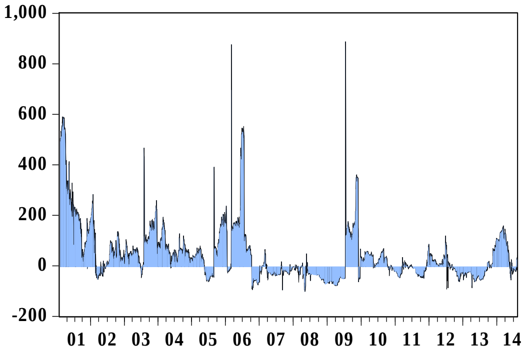
5.7. IYK



5.8. IYM



5.9. IYW



5.10. IYZ

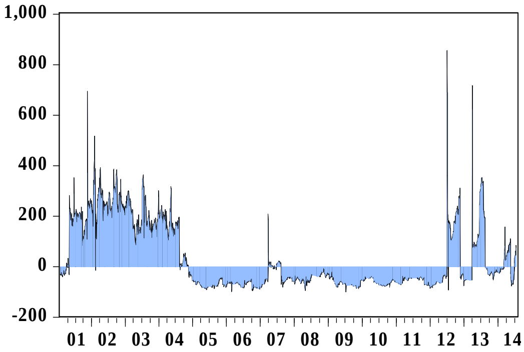
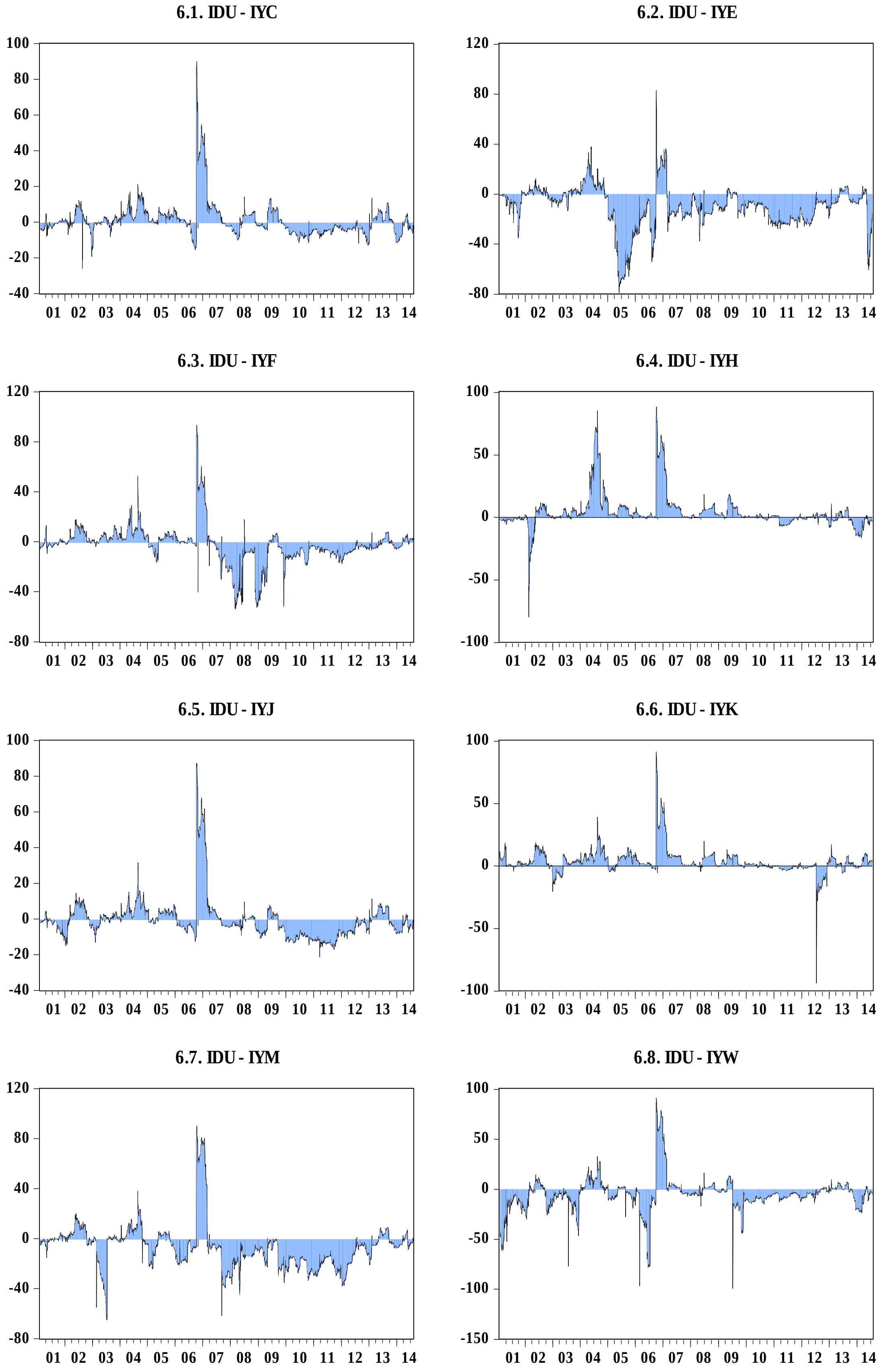
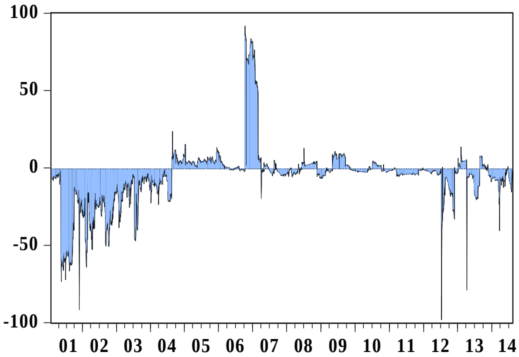


Figure 6. Net Pairwise Directional Volatility Spillover

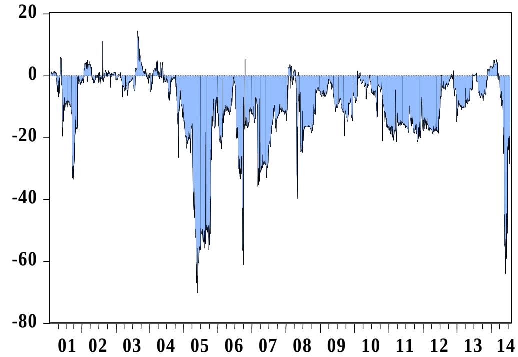
Note: P = 3 lags, H = 12 days, and W = 100 days.



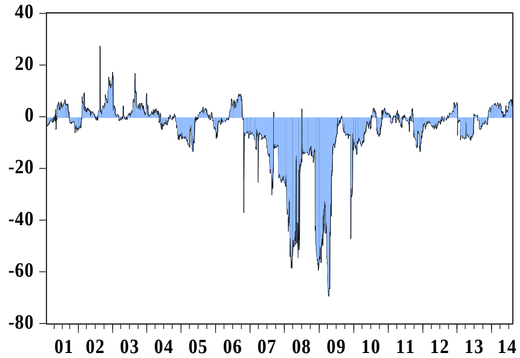
6.9. IDU - IYZ



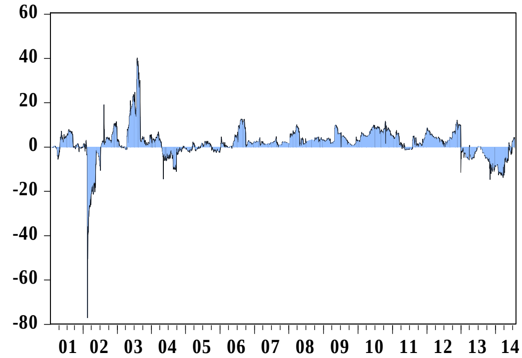
6.10. IYC - IYE



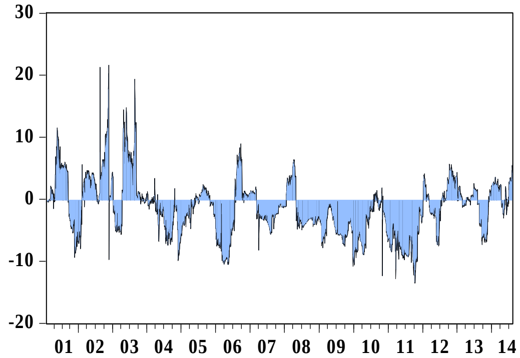
6.12. IYC - IYF



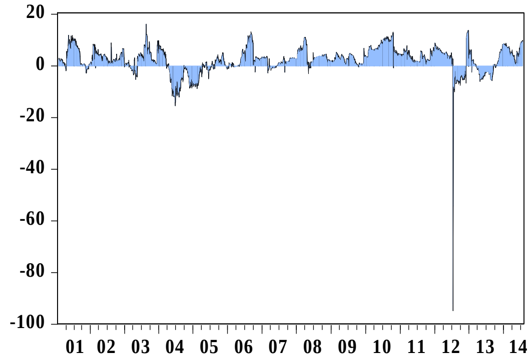
6.12. IYC - IYH



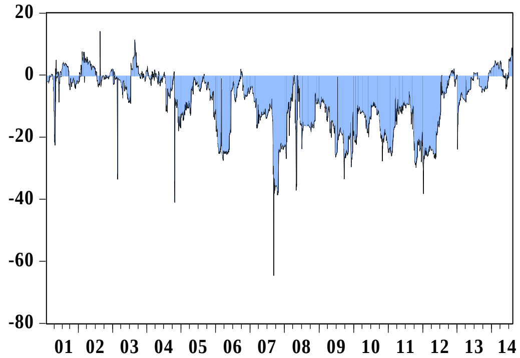
6.13. IYC - IYJ



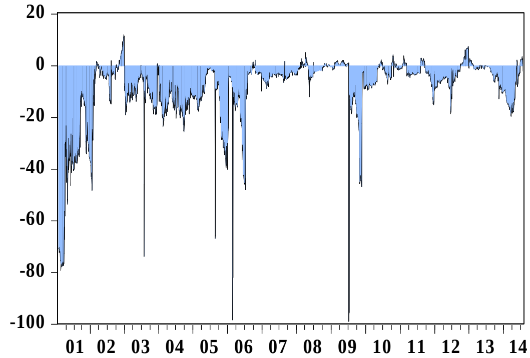
6.14. IYC - IYK



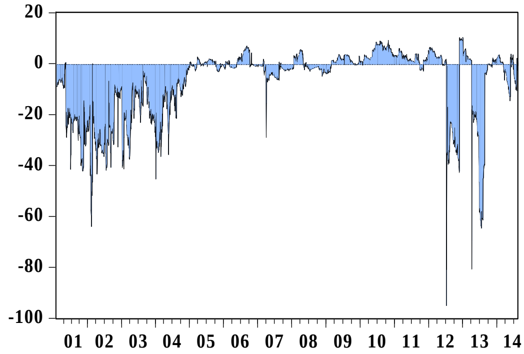
6.15. IYC - IYM



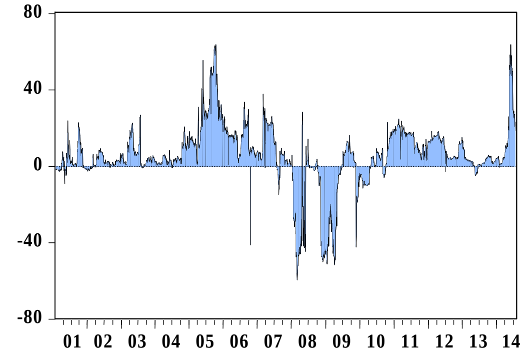
6.16. IYC - IYW



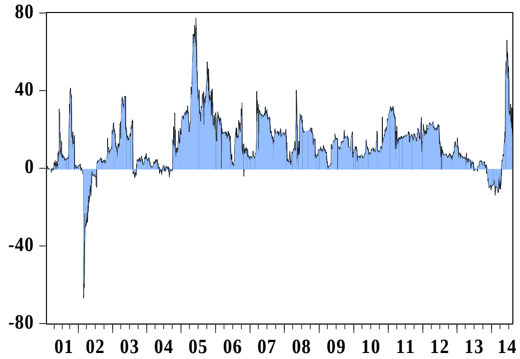
6.17. IYC - IYZ



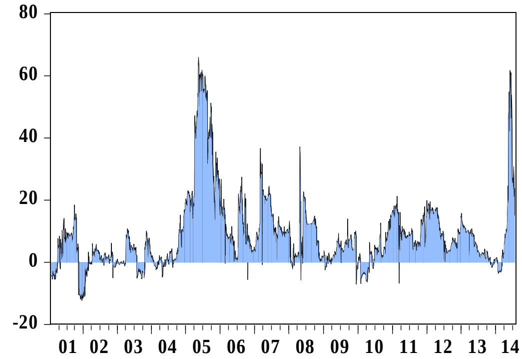
6.18. IYE - IYF



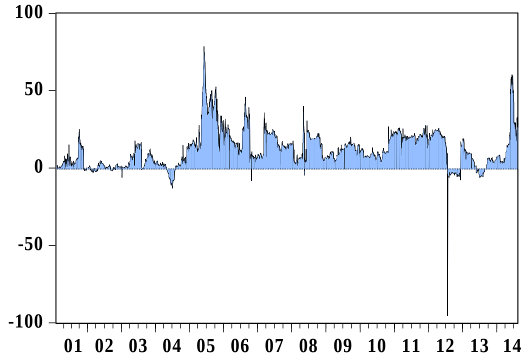
6.19. IYE - IYH



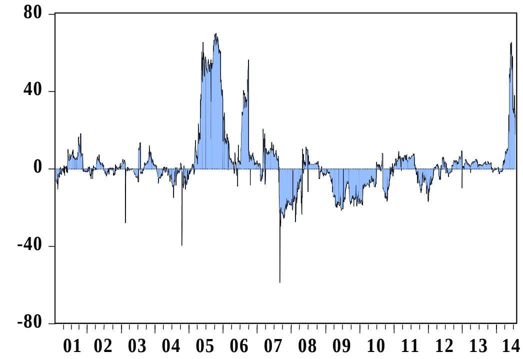
6.20. IYE - IYJ



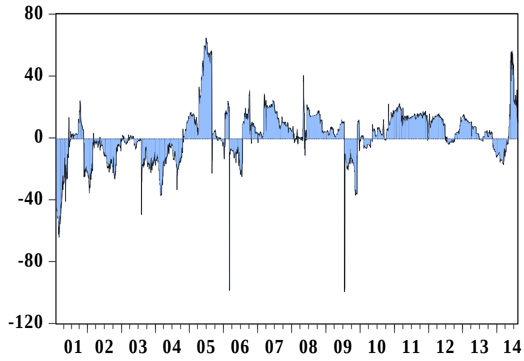
6.21. IYE - IYK



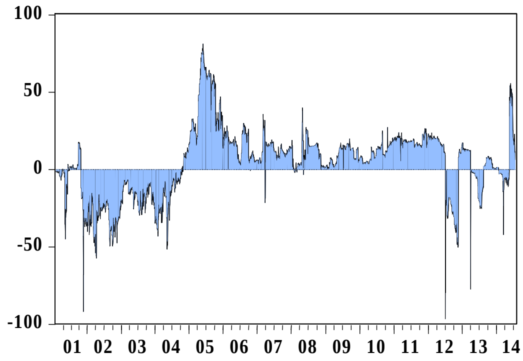
6.22. IYE - IYM



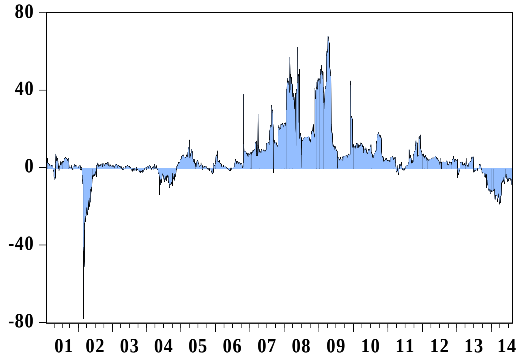
6.23. IYE - IYW



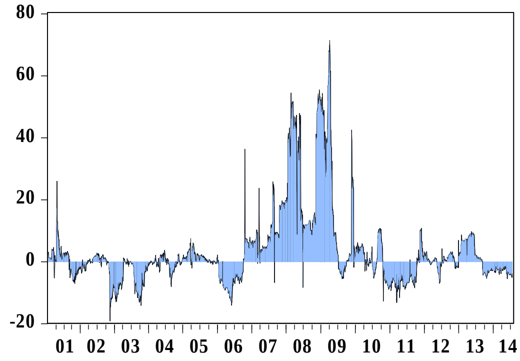
6.24. IYE - IYZ



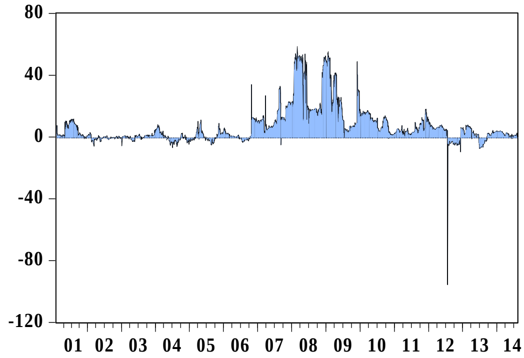
6.25. IYF - IYH



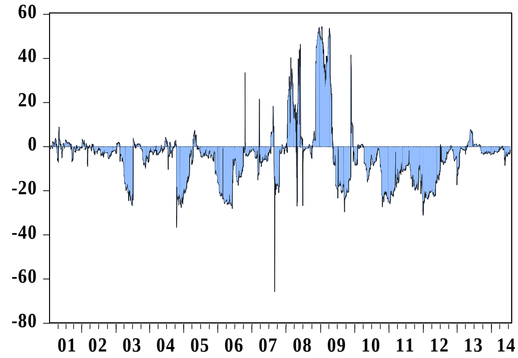
6.26. IYF - IYJ



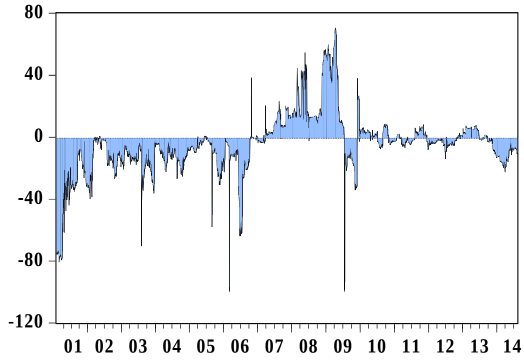
6.27. IYF - IYK



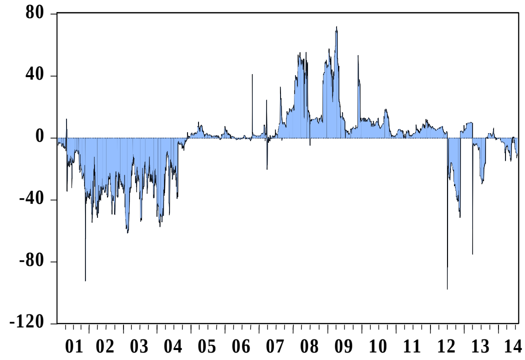
6.28. IYF - IYM



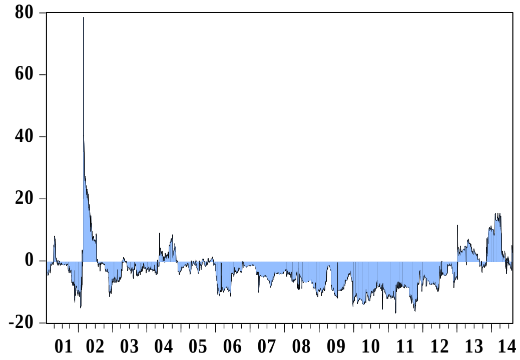
6.29. IYF - IYW



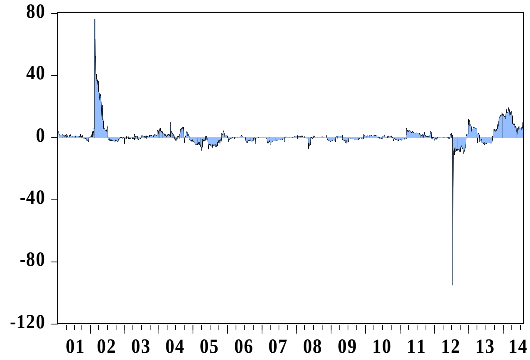
6.30. IYF - IYZ



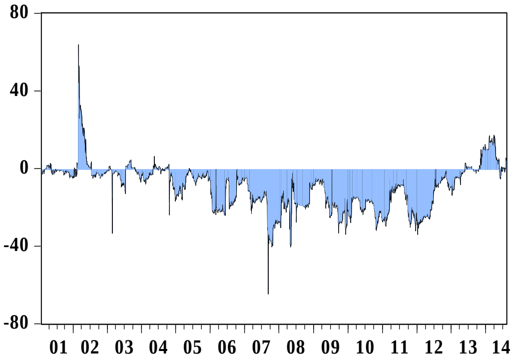
6.31. IYH - IYJ



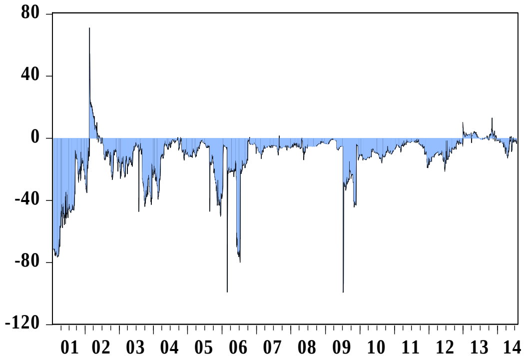
6.32. IYH - IYK



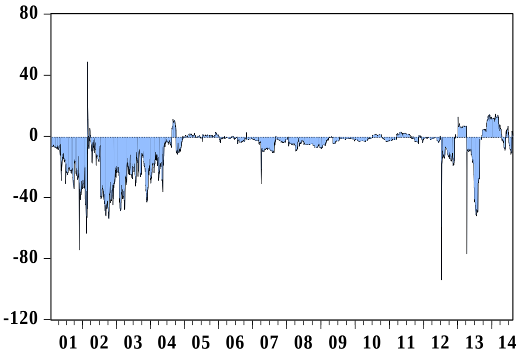
6.33. IYH - IYM



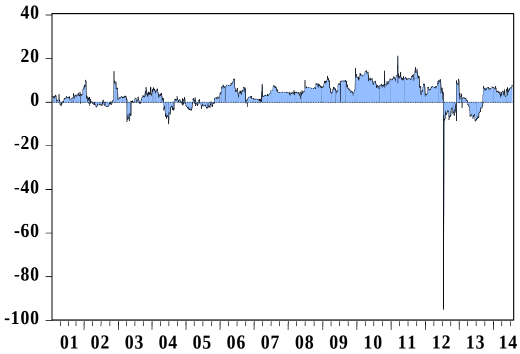
6.34. IYH - IYW



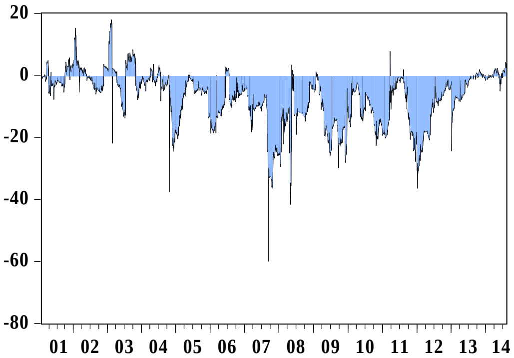
6.35. IYH - IYZ



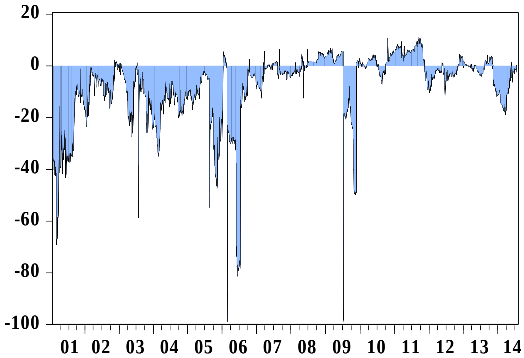
6.36. IYJ - IYK



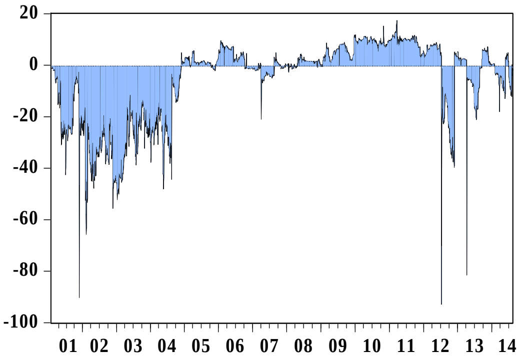
6.37. IYJ - IYM



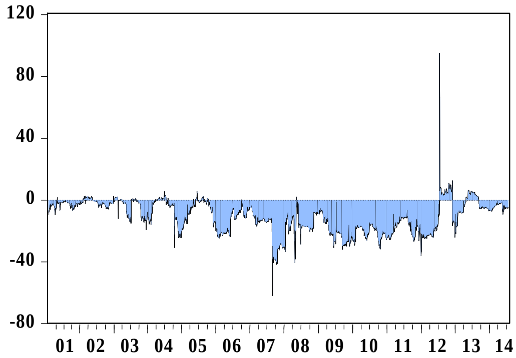
6.38. IYJ - IYW



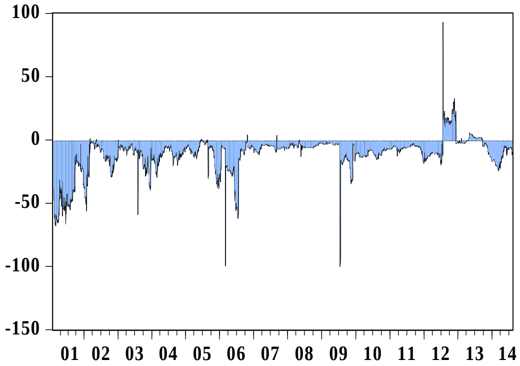
6.39. IYJ - IYZ



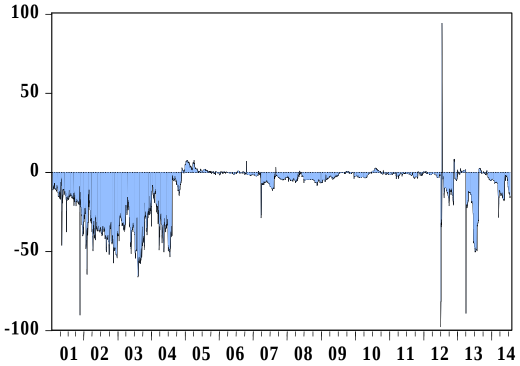
6.40. IYK - IYM



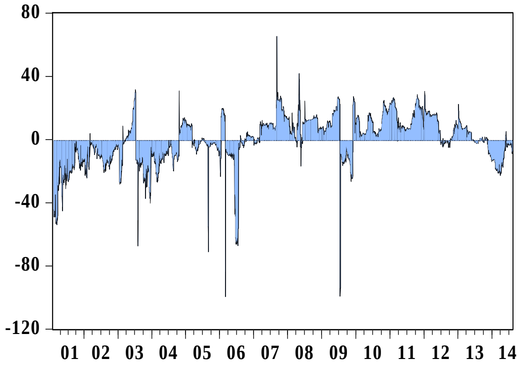
6.41. IYK - IYW



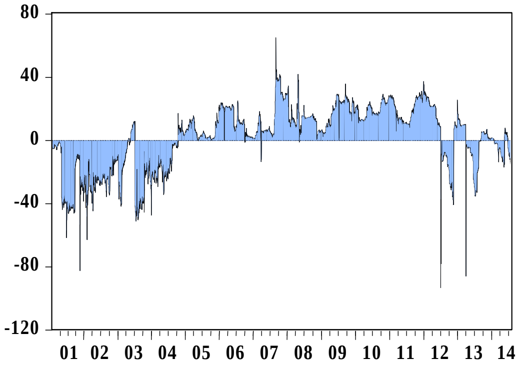
6.42. IYK - IYZ



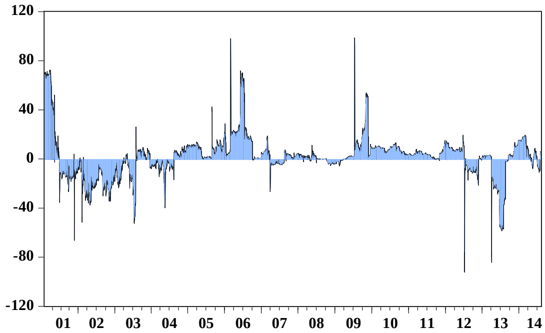
6.43. IYM - IYW



6.44. IYM - IYZ



6.45. IYW - IYZ



2. TABLES

Table 1.1: ETFs Information

Note: The information below is obtained from www.iShares.com as of 1 August 2015

No.	Ticker	Name	Underlying Index	Exposure
1	IDU	iShares U.S. Utilities ETF	Dow Jones U.S. Utilities Index	U.S. companies that supply electric, gas, and water.
2	IYC	iShares U.S. Consumer Services ETF	Dow Jones U.S. Consumer Services Index	U.S. companies that distribute food, drups, general retail items, and media.
3	IYE	iShares U.S. Energy ETF	Dow Jones U.S. Oil & Gas Index	U.S. companies that produce and distribute oil and gas.
4	IYF	iShares U.S. Financials ETF	Dow Jones U.S. Financials Index	U.S. banks, insurers, and credit card companies.
5	IYH	iShares U.S. Healthcare ETF	Dow Jones U.S. Health Care Index	U.S. healthcare equipment and services, pharmaceuticals, and biotechnology companies.
6	IYJ	iShares U.S. Industrials ETF	Dow Jones U.S. Industrials Index	U.S. companies that produce goods used in construction and manufacturing.
7	IYK	iShares U.S. Consumer Goods ETF	Dow Jones U.S. Consumer Services Index	U.S. companies that produce a wide ranges consumer goods, including food, automobiles, and household goods.
8	IYM	iShares U.S. Basic Materials ETF	Dow Jones U.S. Basic Materials Index	U.S. involved with the production of raw materials, including metals, chemicals, and forestry products.
9	IYW	iShares U.S. Technology ETF	Dow Jones U.S. Technology Index	U.S. electronics, computer software and hardware, and informational technology companies.
10	IYZ	iShares U.S. Telecommunications ETF	Dow Jones U.S. Select Telecommunications Index	U.S. companies that provide telephone and internet products, services, and technologies.

Table 1.2: ETFs Information (Continued)

Note: The information below is obtained from www.iShares.com as of 1 August 2015.

No.	Ticker	Respective Sector	Top Holdings
1	IDU	Utilities	Duke Energy Corp., Nextera Energy Inc., Dominion Resources Inc., Southern, Exelon Corp.
2	IYC	Consumer Discretionary	Walt Disney, Home Depot Inc., Comcast A Corp., Amazon Com Inc., Walmart Store Inc.
3	IYE	Energy	Exxon Mobil Corp., Chevron Corp., Schlumberger N.V., Conocophillips, Kinder Morgan Inc.
4	IYF	Financials	Berkshire Hathaway Inc. Class B, Wells Forgo, JPMorgan Chase & Co, Bank of America Corp., Citigroup Inc.
5	IYH	Health Care	Johnson & Johnson, Pfizer Inc., Merck & Co Inc., Gilead Sciences Inc., Amgen Inc.
6	IYJ	Industrials	General Electric, 3M Co, Boeing, United Technologies Corp., Union Pacific Corp.
7	IYK	Consumer Staples	Procter & Gamble, Coca-Cola, PepsiCo Inc., Philip Morris International Inc., Altria Group Inc.
8	IYM	Materials	E I Du Pont De Nemours, Monsanto, Dow Chemical, Praxair Inc., Lyondellbasell Industries N.V.
9	IYW	Information Technology	Apple Inc., Microsoft Corp., Facebook Class A Inc., Google Inc. Class A, Google Inc. Class C.
10	IYZ	Telecommunication Services	Verizon Communications Inc., AT&T Inc., Centurylink Inc., Level Communications Inc., SBA Communications Corp. Class A

Table 2: Volatility Descriptive Statistics

Note: The sample spans from 2 January 2001 to 31 December 2014 and has 3,498 observations.

	IDU	IYC	IYE	IYF	IYH	IYJ	IYK	IYM	IYW	IYZ
Mean	1.38E-04	1.22E-04	2.07E-04	1.82E-04	1.14E-04	1.34E-04	8.99E-05	1.93E-04	2.63E-04	2.59E-04
Median	5.68E-05	5.81E-05	1.26E-04	6.67E-05	5.74E-05	6.43E-05	4.85E-05	9.96E-05	1.00E-04	7.16E-05
Maximum	5.05E-03	2.76E-03	6.18E-03	6.12E-03	2.48E-03	3.56E-03	1.73E-03	5.16E-03	4.54E-03	4.36E-03
Minimum	6.86E-07	4.46E-07	7.69E-06	3.71E-06	3.44E-06	8.21E-07	5.76E-08	2.60E-07	5.94E-06	7.83E-06
Std. Dev.	2.61E-04	2.00E-04	3.42E-04	3.90E-04	1.61E-04	2.24E-04	1.40E-04	3.37E-04	4.21E-04	4.42E-04
Skewness	7.13	5.74	7.27	6.76	4.76	5.95	5.40	6.87	3.79	3.42
Kurtosis	85.11	50.22	78.33	69.37	40.85	55.73	44.99	69.69	23.75	18.51

Table 3.1: ADF Test with Trend and Intercept in Test Equation

Exogenous: Constant, Linear Trend			
Test Critical Values		1% level: -3.961	
		5% level: -3.411	
		10% level: -3.127	
No.	**ETF**	**t-Statistics**	**Prob.**
1	IDU	-5.449	0.000
2	IYC	-4.912	0.000
3	IYE	-5.894	0.000
4	IYF	-5.066	0.000
5	IYH	-6.515	0.000
6	IYJ	-5.084	0.000
7	IYK	-5.515	0.000
8	IYM	-5.724	0.000
9	IYW	-6.296	0.000
10	IYZ	-3.764	0.019

Table 3.2: ADF Test with Intercept in Test Equation

Exogenous: Constant			
Test Critical Values		1% level: -3.432	
		5% level: -2.862	
		10% level: -2.567	
No.	**ETF**	**t-Statistics**	**Prob.**
1	IDU	-5.141	0.000
2	IYC	-4.682	0.000
3	IYE	-5.794	0.000
4	IYF	-5.048	0.000
5	IYH	-5.226	0.000
6	IYJ	-4.961	0.000
7	IYK	-5.171	0.000
8	IYM	-5.681	0.000
9	IYW	-5.230	0.000
10	IYZ	-3.131	0.024

Table 3.3: ADF Test with None in Test Equation

Exogenous: None			
		1% level: -2.566	

Test Critical Values		5% level: -1.941 10% level: -1.617	
No.	**ETF**	**t-Statistics**	**Prob.**
1	IDU	-4.283	0.000
2	IYC	-3.754	0.000
3	IYE	-4.643	0.000
4	IYF	-4.375	0.000
5	IYH	-4.129	0.000
6	IYJ	-3.989	0.000
7	IYK	-4.046	0.000
8	IYM	-4.331	0.000
9	IYW	-4.400	0.000
10	IYZ	-2.675	0.007

Table 4. Pairwise Granger Causality Tests

(*) indicates the statistical insignificance regarding 95% confidence interval.

No.	Null Hypothesis:	P=1	P=2	P=3
1	IYC does not Granger Cause IDU	0.000	0.000	0.000
2	IDU does not Granger Cause IYC	0.000	0.000	0.000
3	IYE does not Granger Cause IDU	0.000	0.000	0.000
4	IDU does not Granger Cause IYE	0.000	0.000	0.000
5	IYF does not Granger Cause IDU	0.000	0.000	0.000
6	IDU does not Granger Cause IYF	0.000	0.000	0.000
7	IYH does not Granger Cause IDU	0.000	0.000	0.000
8	IDU does not Granger Cause IYH	0.000	0.000	0.000
9	IYJ does not Granger Cause IDU	0.000	0.000	0.000
10	IDU does not Granger Cause IYJ	0.000	0.000	0.000
11	IYK does not Granger Cause IDU	0.000	0.000	0.000
12	IDU does not Granger Cause IYK	0.000	0.000	0.000
13	IYM does not Granger Cause IDU	0.000	0.000	0.000
14	IDU does not Granger Cause IYM	0.000	0.000	0.000
15	IYW does not Granger Cause IDU	0.000	0.000	0.000
16	IDU does not Granger Cause IYW	0.000	0.000	0.000
17	IYZ does not Granger Cause IDU	0.000	0.000	0.000
18	IDU does not Granger Cause IYZ	0.000	0.000	0.000
19	IYE does not Granger Cause IYC	0.000	0.000	0.000
20	IYC does not Granger Cause IYE	0.000	0.000	0.000
21	IYF does not Granger Cause IYC	0.000	0.000	0.000
22	IYC does not Granger Cause IYF	0.000	0.000	0.000
23	IYH does not Granger Cause IYC	0.000	0.000	0.000
24	IYC does not Granger Cause IYH	0.000	0.000	0.000
25	IYJ does not Granger Cause IYC	0.000	0.000	0.000
26	IYC does not Granger Cause IYJ	0.000	0.000	0.000
27	IYK does not Granger Cause IYC	0.000	0.000	0.000
28	IYC does not Granger Cause IYK	0.000	0.000	0.000
29	IYM does not Granger Cause IYC	0.000	0.000	0.000
30	IYC does not Granger Cause IYM	0.000	0.000	0.005
31	IYW does not Granger Cause IYC	0.000	0.000	0.000
32	IYC does not Granger Cause IYW	0.000	0.000	0.000
33	IYZ does not Granger Cause IYC	0.000	0.000	0.000
34	IYC does not Granger Cause IYZ	0.000	0.000	0.000
35	IYF does not Granger Cause IYE	0.000	0.000	0.000
36	IYE does not Granger Cause IYF	0.000	0.000	0.000
37	IYH does not Granger Cause IYE	0.000	0.000	0.000
38	IYE does not Granger Cause IYH	0.000	0.000	0.000
39	IYJ does not Granger Cause IYE	0.000	0.000	0.000
40	IYE does not Granger Cause IYJ	0.000	0.000	0.000
41	IYK does not Granger Cause IYE	0.000	0.000	0.002
42	IYE does not Granger Cause IYK	0.000	0.000	0.000
43	IYM does not Granger Cause IYE	0.000	0.000	0.000
44	IYE does not Granger Cause IYM	0.000	0.000	0.000
45	IYW does not Granger Cause IYE	0.000	0.029	0.027

46	IYE does not Granger Cause IYW	0.000	0.005	0.000
47	IYZ does not Granger Cause IYE	0.000	0.013	0.055*
48	IYE does not Granger Cause IYZ	0.000	0.000	0.000
49	IYH does not Granger Cause IYF	0.000	0.001	0.003
50	IYF does not Granger Cause IYH	0.000	0.000	0.000
51	IYJ does not Granger Cause IYF	0.000	0.000	0.000
52	IYF does not Granger Cause IYJ	0.000	0.000	0.000
53	IYK does not Granger Cause IYF	0.086*	0.000	0.000
54	IYF does not Granger Cause IYK	0.000	0.000	0.000
55	IYM does not Granger Cause IYF	0.000	0.000	0.000
56	IYF does not Granger Cause IYM	0.000	0.000	0.000
57	IYW does not Granger Cause IYF	0.042	0.077*	0.102*
58	IYF does not Granger Cause IYW	0.020	0.146*	0.000
59	IYZ does not Granger Cause IYF	0.023	0.014	0.061*
60	IYF does not Granger Cause IYZ	0.007	0.000	0.000
61	IYJ does not Granger Cause IYH	0.000	0.000	0.004
62	IYH does not Granger Cause IYJ	0.000	0.000	0.000
63	IYK does not Granger Cause IYH	0.000	0.000	0.000
64	IYH does not Granger Cause IYK	0.000	0.000	0.000
65	IYM does not Granger Cause IYH	0.000	0.000	0.000
66	IYH does not Granger Cause IYM	0.000	0.000	0.000
67	IYW does not Granger Cause IYH	0.000	0.000	0.000
68	IYH does not Granger Cause IYW	0.000	0.000	0.000
69	IYZ does not Granger Cause IYH	0.000	0.000	0.000
70	IYH does not Granger Cause IYZ	0.000	0.000	0.000
71	IYK does not Granger Cause IYJ	0.000	0.000	0.000
72	IYJ does not Granger Cause IYK	0.000	0.000	0.000
73	IYM does not Granger Cause IYJ	0.000	0.000	0.000
74	IYJ does not Granger Cause IYM	0.000	0.000	0.006
75	IYW does not Granger Cause IYJ	0.000	0.000	0.000
76	IYJ does not Granger Cause IYW	0.000	0.000	0.000
77	IYZ does not Granger Cause IYJ	0.000	0.000	0.000
78	IYJ does not Granger Cause IYZ	0.000	0.000	0.000
79	IYM does not Granger Cause IYK	0.000	0.000	0.000
80	IYK does not Granger Cause IYM	0.000	0.000	0.027
81	IYW does not Granger Cause IYK	0.000	0.000	0.000
82	IYK does not Granger Cause IYW	0.000	0.000	0.000
83	IYZ does not Granger Cause IYK	0.000	0.000	0.000
84	IYK does not Granger Cause IYZ	0.000	0.000	0.000
85	IYW does not Granger Cause IYM	0.011	0.100*	0.356*
86	IYM does not Granger Cause IYW	0.001	0.005	0.003
87	IYZ does not Granger Cause IYM	0.001	0.046	0.117*
88	IYM does not Granger Cause IYZ	0.000	0.000	0.000
89	IYZ does not Granger Cause IYW	0.000	0.000	0.000
90	IYW does not Granger Cause IYZ	0.000	0.000	0.000

Table 5.1: Full Sample Volatility Spillover Table

Note: P = 3 lags, H = 12 days, and W = 3,498 days.

	IDU	IYC	IYE	IYF	IYH	IYJ	IYK	IYM	IYW	IYZ	FROM
IDU	15.0	4.7	17.3	12.3	2.4	6.5	2.2	16.0	7.0	16.6	85.0
IYC	6.7	7.8	16.7	17.3	2.8	7.6	2.2	16.9	8.3	13.7	92.2
IYE	5.8	4.2	29.7	14.3	2.0	6.5	1.8	19.5	7.7	8.5	70.3
IYF	4.5	4.5	14.2	37.0	1.7	6.9	1.5	16.1	6.4	7.4	63.0
IYH	6.4	5.3	15.1	13.7	6.4	6.8	2.4	12.3	14.4	17.1	93.6
IYJ	6.4	5.3	16.8	19.1	2.4	11.1	2.2	17.8	7.4	11.5	88.9
IYK	7.7	5.5	17.2	15.7	2.9	7.5	4.2	16.0	8.5	14.8	95.8
IYM	6.1	4.6	20.5	16.6	1.8	7.3	1.7	26.0	7.4	7.9	74.0
IYW	3.9	3.4	8.1	8.5	2.7	3.4	1.3	7.6	47.4	13.7	52.6
IYZ	6.3	3.5	9.2	8.5	2.6	4.5	1.9	8.0	10.9	44.5	55.5
TO	53.9	41.1	135.0	126.1	21.3	57.1	17.1	130.0	78.1	111.1	77.1
NET	-31.1	-51.1	64.7	63.1	-72.2	-31.8	-78.7	56.0	25.5	55.7	

Table 5.2: Full Sample Net Pairwise Directional Volatility Spillover Table

Note: P = 3 lags, H = 12 days, and W = 3,498 days.

	IDU	IYC	IYE	IYF	IYH	IYJ	IYK	IYM	IYW	IYZ
IDU	0.0	-2.0	11.5	7.8	-4.0	0.1	-5.5	9.8	3.2	10.3
IYC	2.0	0.0	12.4	12.8	-2.5	2.3	-3.3	12.3	4.9	10.1
IYE	-11.5	-12.4	0.0	0.2	-13.2	-10.3	-15.4	-1.0	-0.5	-0.7
IYF	-7.8	-12.8	-0.2	0.0	-12.0	-12.3	-14.2	-0.6	-2.1	-1.1
IYH	4.0	2.5	13.2	12.0	0.0	4.4	-0.5	10.5	11.7	14.4
IYJ	-0.1	-2.3	10.3	12.3	-4.4	0.0	-5.3	10.4	4.0	7.0
IYK	5.5	3.3	15.4	14.2	0.5	5.3	0.0	14.3	7.3	12.9
IYM	-9.8	-12.3	1.0	0.6	-10.5	-10.4	-14.3	0.0	-0.1	-0.1
IYW	-3.2	-4.9	0.5	2.1	-11.7	-4.0	-7.3	0.1	0.0	2.8
IYZ	-10.3	-10.1	0.7	1.1	-14.4	-7.0	-12.9	0.1	-2.8	0.0