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CO-MOVEMENTS OF U.S. AND EUROPEAN STOCK MARKETS BEFORE AND AFTER THE 2008 GLOAL STOCK MARKET CRASH

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Abstract:

Empirical studies show that correlation between national stock markets increased and the benefits of global portfolio diversification decreased significantly after the global stock market crash of 1987. The 1987 and 2008 crashes are the two most important global stock market crashes since the 1929 Great depression. Although the effects of the 1987 crash on the co-movements of national stock markets have been investigated extensively, the effects of the 2008 crash have not been studied sufficiently. In this paper we study this issue with a research sample that includes the U.S stock market and twenty European stock markets. We find that correlation between the twenty-one stock markets increased and the benefits of portfolio diversification decreased significantly after the 2008 stock market crash.

Key words: *European stock markets, portfolio diversification, 2008 stock market crash*

1. Introduction

Studying stock market crashes has been one of the most popular research topics in finance. Wang et al. (2009) study the determinants of stock returns in stock market crashes. Uygur et al. (2015) investigate which stocks lose more value in stock market crashes. The impact of stock market crashes on the co-movement patterns of

national stock markets has been studied extensively [see, e.g., Arshanapalli and Doukas (1993); Meric and Meric (1997)].

The portfolio diversification implication of the co-movements of national stock markets has long been a popular research topic in finance. Low correlation between national stock markets is often presented as evidence in support of the benefit of global portfolio diversification [see, e.g., Levy and Sarnat (1970); Solnik (1974); Watson (1978); Meric and Meric (1989); DeFusco et al. (1996)].

Events of global importance tend to have significant impact on the world's stock markets. Empirical studies provide evidence that the co-movement patterns of national stock markets change significantly after stock market crashes. Arshanapalli and Doukas (1993), Lau and McInish (1993), and Meric and Meric (1997) compare the pre-October-1987 and post-October-1987 periods and demonstrate that correlation between national stock markets increased and global portfolio diversification benefits to investors decreased significantly after the 1987 crash.

The 1997-1998 emerging markets financial crisis is another global event that had a significant impact on the world's stock markets. Meric et al. (2000) and Yang et al. (2003) provide empirical evidence that the crisis affected the co-movement patterns of the world's stock markets significantly and that the benefits of portfolio diversification to global investors with the emerging stock markets decreased considerably after the 1997-1998 crisis.

Hon et al. (2004), Meric and Meric (2004), and Meric et al. (2007) study whether the September 11, 2001 terrorist attacks in the United States affected the co-movements of global stock markets by comparing the pre-September 11 and post-September 11 periods. They conclude that correlation between national stock markets increased and the benefits of global portfolio diversification decreased significantly after September 11, 2001.

The 1987 and 2008 crashes are the two most important global stock market crashes since the 1929 Great Depression. Although the effects of the 1987 stock market crash on the co-movements of national stock markets have been studied extensively, the effects of the 2008 stock market crash have not yet been studied sufficiently. In a recent paper, Meric et al. (2015) study the co-movements of the world’s stock markets before and after the 2008 stock market crash by using the Principal Components Analysis methodology. They find that the movements of the world’s major stock markets have become significantly closer and the benefit of global portfolio diversification has decreased significantly after the 2008 stock market crash. In this paper, we make a contribution to the literature on this subject by comparing the co-movements of the U.S. and European stock markets before and after the 2008 stock market crash. In addition to Principal Components Analysis, we also use a maximum likelihood method to test the equality of the covariance matrices of national stock market returns for the pre- and post-crash periods to determine if there are significant changes in the co-movement patterns of the U.S. and European Stock markets after the 2008 stock market crash.

2. The Effects of the 2008 Stock Market Crash on the U.S. and European Economies

The growing uncertainty in financial markets began to impact the global economy in 2008 as reflected by the decrease in the growth rate of real world output from 3.9 percent in the pre-crash 2003-2007 period to 1.5 percent in 2008. Table 1 below shows real annual growth rates for the world economy and different regions around the world from 2003 to 2013.

The ongoing uncertainty in financial markets along with bank failures around the world, frozen credit markets, and sharply falling real estate and other asset prices led to a 2 percent decline in world output in 2009, the first worldwide contraction since 1946. The one-year decrease in global trade of 25 percent in 2009 was the single largest decline in world trade since the end of World War II (2010 CIA World Factbook). Column four in

Table 1: Annual Growth Rates in Real GDP

Area	Average Annual Real GDP Growth Rate (%) 2003-2007	Annual Real GDP Growth Rate (%)		Average Annual Real GDP Growth Rate (%) 2010-2013
		2008	2009	
World	3.9	1.5	-2	2.5
South America	6.1	4.9	-0.3	3.4
Latin America	5.2	3.5	-1.6	3.2
Central America	4.1	1.7	-4.3	3.3
Europe	3.2	0.8	-4.5	0.8
Eastern Europe	6.8	4.6	-5.6	2.4
Northern Europe	3.1	-0.4	-4.8	1.6
Southern Europe	2.5	-0.1	-4.6	-1.1
Western Europe	2.5	1	-4.1	1
Northern America	2.9	-2	-2.8	2.2
Asia	6	3.3	1.1	4.3
China	12	9.6	9.2	8.2
Africa	6	5.4	3	3
Australia& New Zealand	3.4	1.3	1.7	2.9

Source: http://unstats.un.org/unsd/snaama/selbasicFast.asp

Table 1 indicates that the financial crisis that began in the U.S. in 2008 spread to the rest of the world by 2009 as annual growth rates for all regions of the world fell that year.

However, the impact of the financial crisis contagion around the world was uneven. About one-third of world output was produced by countries that continued to expand in 2009 and throughout the post-crash period; while about two-thirds of world output came countries that were in a recession in 2008. One factor that explains these regional differences is the degree of capital market integration. For example, emerging Latin American economies with strong growth prospects attract international investments and become more vulnerable to financial contagion during a period of crisis. Dufrenotet et. al (2011) found the 2007 U.S. subprime financial crisis was transmitted to Latin America and contributed to stock market volatility in the region. Using data from a wider time period, 2006 to 2010,Hwang (2014) also found evidence of financial connections between U.S. and Latin American economies. Countries and areas of the world with a low degree of capital market integration would be less vulnerable to financial contagion. This could partially explain why growth in Africa declined in 2009, but the area did not fall into recession.

A second factor influencing differences in the regional effects from the financial crisis is related to countries that are in the process of transition from central planning to market oriented economies. As countries begin the transition process toward economic liberalism and begin to be more integrated into the global economy, they become more open to capital flows and become more dependent on foreign trade. This increased participation in the global economy with expanding export sectors and increased dependence on capital inflows can facilitate economic growth but it can also make transition economies more susceptible to the negative effects of contagion during a financial crisis. Stiglitz (l998) argues that the contagion risk facing transition economies can be mitigated to some extent by ensuring an appropriate system of regulation is established along with the movement toward developing competitive markets. Shostya (2014) examined the impact of the 2007-2009 financial crisis on the twenty-eight countries of the former Soviet Union and found that the degree of transition and the significance of trade with the EU increased the contagion experienced by these countries. In support of this finding, Table 1 shows the 5.6 percent real GDP contraction in Eastern Europe in 2009 was deeper than any other region in the world.

A third reason for the regional differences resulting from the financial crisis is due to the policy responses that were implemented around the world. Most countries and central banks around the world implemented expansionary monetary and fiscal policies to stimulate their economies to offset the recessionary pressure resulting from the financial crisis. The widespread use of expansionary fiscal policy around the world caused most governments to run budget deficits (90 percent of countries experienced growing budget imbalances in 2009 (CIA, 2010)). By 2012 concern about budget deficits had shifted the policy consensus on how to deal with the financial crisis. About half the countries in the world continued to use expansionary fiscal and monetary policies, about 25 percent used restrictive fiscal and monetary policies, and about 25 percent used a mix of expansionary and contractionary fiscal and monetary policies (CIA, 2013-2014). The average growth rate in 2012 for countries that continued using expansionary fiscal and monetary policies was 4.9 percent; countries that shifted to

restrictive fiscal and monetary policies realized an average growth rate of just 0.8 percent that year (CIA, 2013-2014). Given the budgetary rules established by the EU, deficits were a significant concern in Europe. Bailout packages that were provided to countries in Southern Europe were coupled with strict austerity measures. This fiscal austerity explains in part why the Southern Europe economy continued to contract in the post-crash period and why Europe had the lowest growth rate in the 2010-2013 period compared to other regions in the world as shown in Table 1.

Table 2 shows pre- and post-crash economic data for the U.S. and the 21 European countries included in the statistical analyses that follow. Annual GDP growth rates fell in all 21 European countries during the 2009-2013 five-year post-crash period. The average annual European post-crash growth rate, -0.13 percent, is significantly lower than the 3.42 percent average annual rate that occurred during the 2003-2007 five-year pre-crash period. The t-test for equality of mean annual European growth rates for the two periods is associated with a p-value<0.0000002.

Table 2: Selected Economic Data for the Europe and the U.S.

Country	GDP Growth Rates (%)[a]		Exports (% GDP)[b]		Imports (% GDP)[b]		Inflation Rate (% change in CPI)[a]	
	2003-2007	2009-2013	2003-2007	2009-2013	2003-2007	2009-2013	2003-2007	2009-2013
Austria	2.51	0.43	48.69	51.26	45.44	48.31	1.87	2.01
Belgium	2.37	0.36	73.27	78.38	68.97	77.05	2.02	1.92
Czech Rep.	5.47	-0.45	59.73	70.07	58.30	65.74	2.04	1.82
Denmark	2.01	-0.72	47.39	51.52	42.47	46.10	1.73	1.91
Finland	3.58	-1.16	40.66	38.38	35.55	38.38	1.20	1.78
France	1.99	0.33	26.44	26.86	26.60	28.72	1.83	1.31
Germany	1.62	0.44	38.04	43.29	32.90	37.96	1.62	1.40
Greece	4.35	-5.74	20.88	25.01	31.06	31.65	3.21	1.95
Hungary	3.45	-0.83	66.60	84.28	68.73	78.27	5.34	4.09
Ireland	4.72	-0.85	78.74	98.28	66.91	79.52	3.38	-0.16
Italy	1.23	-1.51	25.13	26.29	25.19	26.49	2.16	1.85
Netherlands	2.47	-0.59	66.00	75.64	58.30	66.88	1.56	1.95
Norway	2.49	0.73	43.14	40.45	28.45	28.06	1.50	1.74
Poland	5.12	2.90	36.00	42.47	38.26	43.00	1.99	3.07
Portugal	1.13	-1.53	28.33	33.57	36.37	37.26	2.70	1.44
Russia	7.50	1.03	33.75	29.08	22.02	21.62	11.17	7.73
Spain	3.60	-1.51	25.17	27.77	29.77	27.32	3.15	1.71
Sweden	3.52	0.87	45.40	45.49	38.27	40.33	1.26	0.89
Switzerland	2.81	1.12	54.41	65.33	45.86	55.48	0.88	-0.09
Turkey	6.90	3.74	22.68	24.09	26.13	29.50	12.71	7.53
U.K.	3.03	0.30	25.65	29.33	28.22	31.27	1.88	3.06
U.S.	2.87	1.15	10.16	12.81	15.25	16.10	2.88	1.59

Source: World Bank Databank. [a] Effective annual rate over indicated five year period. [b] Average computed over indicated five year period.

The effect of the crash on variations in growth rates among the European economies might shed light on how the crash affected opportunities for diversification. The post-crash variation in annual European growth rates is larger than the pre-crash variation, but the difference is not statistically significant. The ratio of post-crash to pre-crash variances in annual European growth rates is 1.19; however, the F-test for equality of variances is associated with a p-value = 0.35. We emphasize that this result is suggestive but not conclusive evidence of opportunities for diversification. Variations in annual growth rates do not reflect intra-country variations in stock prices or inter-temporal co-movements of stock prices.

Table 3: Major Trading Partners for Europe and the U.S.

Country	Export and Import Partners
Austria	Export Partners: Germany 29.3%, Italy 6.3%, Switzerland 5.1% (2013 est.)
	Import Partners: Germany 40.4%, Italy 6.1%, Switzerland 5.4% (2013 est.)
Belgium	Export Partners: Germany 18%, France 16.1%, Netherlands 13% (2012)
	Import Partners: Netherlands 20.9%, Germany 14.2%, France 10.6% (2012)
Czech Republic	Export Partners: Germany 31.8%, Slovakia 9.1%, Poland 6.1% (2012)
	Import Partners: Germany 29.5%, Poland 7.7%, Slovakia 7.4% (2012)
Denmark	Export Partners: Germany 15.9%, Sweden 13.5%, UK 9.6% (2012)
	Import Partners: Germany 21.2%, Sweden 13.5%, Netherlands 7.5% (2012)
Finland	Export Partners: Sweden 11.1%, Russia 9.9%, Germany 9.3% (2012)
	Import Partners: Russia 17.7%, Sweden 14.8%, Germany 13.9% (2012)
France	Export Partners: Germany 16.7%, Belgium 7.5%, Italy 7.5% (2012)
	Import Partners: Germany 19.5%, Belgium 11.3%, Italy 7.6% (2012)
Germany	Export Partners: France 9.2%, US 7.9%, UK 6.5% (2013 est.)
	Import Partners: Netherlands 12.9%, France 7.6%, China 6.3 (2013 est.)
Greece	Export Partners: Turkey 11.6%, Italy 9.9%, Germany 6.5% (2013 est.)
	Import Partners: Russia 13.8%, Germany 9.5%, Italy 7.9% (2013 est.)
Hungary	Export Partners: Germany 25.6%, Romania 6.2%, Slovakia 6.1% (2012)
	Import Partners: Germany 25.1%, Russia 8.8%, China 7.4% (2012)
Ireland	Export Partners: US 17.9%, UK 17.3%, Belgium 15.6% (2012)
	Import Partners: UK 39.8%, US 13.2%, Germany 7.6% (2012)
Italy	Export Partners: Germany 12.6%, France 11.1%, US 6.8% (2013 est.)
	Import Partners: Germany 14.7%, France 8.4%, China 8.4% (2013 est.)
Netherlands	Export Partners: Germany 26.5%, Belgium 13.7%, France 8.8% (2012)
	Import Partners: Germany 13.8%, China 12%, Belgium 8.4% (2012)
Norway	Export Partners: UK 25.6%, Germany 12.6%, Netherlands 12% (2012)
	Import Partners: Sweden 13.6%, Germany 12.4%, China 9.3% (2012)
Poland	Export Partners: Germany 26%, UK 7%, Czech Republic 6.5% (2012)
	Import Partners: Germany 27.3%, Russia 12.2%, Netherlands 5.9% (2012)
	Export Partners: Spain 22.7%, Germany 12.4%, France 11.9% (2012)

Portugal	Import Partners: Spain 32%, Germany 11.5%, France 6.7% (2012)
Russia	Export Partners: Netherlands 14.6%, China 6.8%, Germany 6.8% (2012 est.)
	Import Partners: China 16.6%, Germany 12.2%, Ukraine 5.7% (2012 est.)
Spain	Export Partners: France 16.8%, Germany 10.8%, Italy 7.7% (2012)
	Import Partners: Germany 11.8%, France 11.5%, Italy 6.7% (2012)
Sweden	Export Partners: Norway 10.4%, Germany 10.3%, UK 8.1% (2012)
	Import Partners: Germany 17.4%, Denmark 8.5%, Norway 8.4% (2012)
Switzerland	Export Partners: Germany 18.5%, US 11.61%, Italy 7.61% (2013 est.)
	Import Partners: Germany 28.2%, Italy 10.5%, France 8.5% (2013 est.)
Turkey	Export Partners: Germany 8.6%, Iraq 7.1%, Iran 6.5% (2012)
	Import Partners: Russia 11.3%, Germany 9%, China 9% (2012)
United Kingdom	Export Partners: Germany 11.3%, US 10.5%, Netherlands 8.8% (2012)
	Import Partners: Germany 12.6%, China 8%, Netherlands 7.5% (2012)
United States	Export Partners: Canada 18.9%, Mexico 14%, China 7.2% (2012)
	Import Partners: China 19%, Canada 14.1%, Mexico 12% (2012)

Source: CIA World Factbook. Figures are percentages of countries' total exports or imports. Dates indicate years of estimates.

The deflationary impact of the crash is evident as annual inflations rates fell in 15 of the 21 European countries during the post-crash period. Two countries, Ireland and Switzerland, experienced deflation over this time period. However, the average annual pre-crash European inflation rate of 3.1 percent is not statistically different from the average annual 2.3 percent post-crash rate. Also, the variance in annual European inflation rates fell during the post-crash period, but not significantly.

The data in Table 2 show the heavy reliance of the European economies on international trade, both before and after the crash. Exports in the 21 European economies averaged 43.1 percent of their GDPs during the pre-crash period, and 47.9 percent during the post-crash period. These figures contrast sharply with those for the U.S. economy. During the pre-crash period, U.S. exports averaged just 10.2 percent and 12.8 percent of GDP, respectively, in the pre- and post-crash periods. The import data show comparable contrasts between the European and U.S. economies. The heavy reliance of the European economies on trade is likely to due to their geographic proximity and to the relatively small sizes of their economies.

While reliance on trade may expose any single European country to risk associated with adverse economic conditions suffered by their trading partners, it may present diversification opportunities for U.S. investors if European countries and the U.S. do not share major trading partners. The data displayed in Table 3, which lists the top three trading partners for the countries included in our study, sheds light on this issue. Canada, China, and Mexico are the three largest trading partners of the U.S. China is a major trading partner with just 7 of the 21 European countries, and no European country is a major trading partner with either Canada or Mexico.

Also, we note that just 5 of the European countries claim the U.S. as a major trading partner. Much of the trade among the European countries appears to be inter-European. Germany, which has the largest economy in Europe, is a major trading partner with all 20 other European countries in our sample.

3. Data and Methodology

In addition to the U.S. stock market, the stock markets of the following twenty European countries are included in the study: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, and the U.K. We study and compare the co-movement patterns of the twenty-one stock markets before and after the 2008 global stock market crash.

We use the Morgan Stanley Capital International (MSCI) weekly U.S.-dollar stock market indexes in the study. The data are drawn from the DataStream database. The weekly index returns are computed as the natural log difference in the indexes, $\ln(I_{I,t}/I_{I,t-1})$. The pre-crash period is the 2003-2007 five year period before 2008 and the post-crash period is the 2009-2013 five year period after 2008.

We first compute and compare the correlation coefficients of the pre-crash and post-crash periods. We then use a maximum likelihood method to test the equality of the pre- and post-crash covariance matrices to determine if there was a significant change in the covariance patterns of the twenty-one stock markets from the pre-crash to the post crash period. We complete the study with a principal components analysis of the co-movement patterns of the stock markets during the pre- and post-crash periods.

4. Correlation Analysis

Table 4 shows the Pearson correlation coefficients between the U.S. stock market returns and the stock market returns of the twenty European stock markets during the pre- and post-crash periods. All twenty correlation coefficients are higher for the post-crash period than for the pre-crash period. The average correlation coefficient for all stock markets increased by 41 percent from 0.522 in the pre-crash period to 0.737 in the post-crash period. The correlation between the U.S. and Hungarian stock markets increased by 183 percent from the pre-crash period to the post-crash period. These results indicate that co-movements of the U.S. and European stock markets are substantially closer after the 2008 stock market crash than they were before the crash. This implies that there are less portfolio diversification opportunities for U.S. investors with European stock markets after the 2008 stock market crash compared with the pre-crash period.

The statistics in Table 4 show that the U.S. stock market is most closely correlated with the Dutch, French, German, and U.K. stock markets both before and after the 2008 stock market crash (i.e., these European stock markets are the worst

portfolio diversification prospects for U.S. investors in both periods). The U.S. stock market is least closely correlated with the Portuguese, Polish, Turkish, Czech, and Hungarian stock markets in both pre- and post-crash periods (i.e., these European stock markets are the best portfolio diversification prospects for U.S. investors in both periods).

Table 4: Correlation of the U.S Stock Market with the Other Stock Markets

Stock Markets	Correlation Coefficients		
	Pre-Crash Period	Post-Crash Period	% Change
Netherlands	0.743	0.804	+ 8 %
France	0.731	0.827	+ 13 %
Germany	0.717	0.820	+ 14 %
U.K.	0.674	0.834	+ 24 %
Sweden	0.662	0.790	+ 19 %
Belgium	0.652	0.755	+ 16 %
Switzerland	0.636	0.745	+ 17 %
Spain	0.633	0.711	+ 12 %
Italy	0.614	0.780	+ 27 %
Denmark	0.560	0.704	+ 26 %
Finland	0.557	0.766	+ 38 %
Ireland	0.499	0.665	+ 33 %
Austria	0.460	0.781	+ 70 %
Norway	0.392	0.782	+ 99 %
Greece	0.392	0.820	+ 109 %
Portugal	0.380	0.647	+ 70 %
Poland	0.374	0.663	+ 77 %
Turkey	0.264	0.582	+ 120 %
Czech Republic	0.255	0.592	+ 132 %
Hungary	0.236	0.668	+ 183 %
Average	*0.522*	*0.737*	*41 %*

Table 5 lists the ten most correlated and ten least correlated pairs of stock markets for the pre- and post-crash periods. Low correlation coefficients show the pairs of stock markets with the best portfolio diversification benefit and high correlation coefficients show the pairs of stock markets with the least portfolio diversification benefit. The Turkish stock market appears to be an attractive portfolio diversification prospect for investors in both periods.

Table 6 shows the average correlation coefficients of each stock market with the other stock markets. A high average correlation indicates that a stock market is

very well integrated with the other stock markets. Such a stock market is not a good prospect for portfolio diversification. Investors can maximize the portfolio diversification benefit by investing in the stock markets with a low average correlation coefficient with the other markets. The figures in Table 5 indicate that the Turkish, Czech, Hungarian, and Portuguese stock markets have the lowest average correlation coefficients in both pre- and post-crash periods (i.e., these stock markets appear to be the best portfolio diversification prospects for investors in both periods).

The average of the average correlation coefficients increased by 26 percent from 0.587 in the pre-crash period to 0.740 in the post-crash period. This implies that global diversification opportunities with the stock markets included in this study decreased substantially from the pre-crash period to the post-crash period. The average correlation coefficient increased the most for the Austrian and Hungarian stock markets (54 percent) and the least for the Danish stock market (8 percent).

5. Test of Equality of the Covariance Matrices for the Pre- and Post-Crash Periods

A modified log-likelihood ratio test [see, e.g., Anderson (2003)] is used to test the homogeneity of the covariance matrices of the stock market returns of pre- and post-crash periods. Note that since the sample correlation matrix can be considered as the covariance matrix under scale change, one can interpret the test results as applying to the correlation matrices as well.

Let Σ_1 and Σ_2 represent the covariance matrices of pre- and post-crash periods, respectively. Each of the two random samples (one from each of the two different historical periods) consists of 260 weekly equity market index returns of 21 different countries. Denote the sample data by $\{\mathbf{X}_{i1},\ldots,\mathbf{X}_{in_i}, i=1,2\}$, where p×1 random vector $\mathbf{X}_{ij}$ represents an observation of the weekly stock market index returns of p = 21 different countries from the ith population and $n_1 = n_2 = 260$. Set $n = n_1 + n_2$. The test statistic used to test for homogeneity of Σ_1 and Σ_2 is $-2\rho\log\lambda$, where

$$\rho = 1 - \left(\sum_{i=1}^{2}\frac{1}{n_i - 1} - \frac{1}{n-2}\right)\frac{2p^2+3p-1}{6(p+1)}, \tag{1}$$

$$\overline{\mathbf{X}}_i = \frac{1}{n_i}\sum_{j=1}^{n_i}\mathbf{X}_{ij} \text{ (for i = 1,2)}, \qquad A_i = \sum_{j=1}^{n_i}(\mathbf{X}_{ij} - \overline{\mathbf{X}}_i)(\mathbf{X}_{ij} - \overline{\mathbf{X}}_i)' \text{ (for i = 1,2)}, \tag{2}$$

$$\hat{\Sigma}_i = \frac{A_i}{n_i - 1} \text{ (for i = 1,2)}, \qquad \hat{\Sigma} = \frac{A_1 + A_2}{n-2}, \text{ and} \qquad \lambda = \frac{\prod_{i=1}^{2}\left|\hat{\Sigma}_i\right|^{\frac{1}{2}(n_i-1)}}{\left|\hat{\Sigma}\right|^{\frac{1}{2}(n-2)}} \tag{3}$$

Table 5: Most Correlated and Least Correlated Stock Markets

Most Correlated Stock Markets			
Pre-Crash Period		*Post-Crash Period*	
Country Pair	Correlation Coefficient	Country Pair	Correlation Coefficient
France – Germany	0.943	France – Germany	0.960
France – Netherlands	0.926	France – Netherlands	0.955
Germany – Netherlands	0.902	France – Italy	0.940
Belgium – France	0.898	Germany – Netherlands	0.936
France – Italy	0.891	Italy – Spain	0.917
Belgium – Netherlands	0.884	Italy – Netherlands	0.913
France – Switzerland	0.883	France – U.K.	0.910
France – Spain	0.880	Netherlands – U.K.	0.902
France – U.K.	0.874	France – Spain	0.900
Germany – Spain	0.871	Belgium – Netherlands	0.900
Average	*0.895*	*Average*	*0.923*
Least Correlated Stock Markets			
Pre-Crash Period		*Post-Crash Period*	
Country Pair	Correlation Coefficient	Country Pair	Correlation Coefficient
U.S. – Hungary	0.236	Ireland – Turkey	0.451
U.S. – Czech Rep.	0.255	Greece – Ireland	0.489
U.S. – Turkey	0.264	Greece – Turkey	0.500
Finland – Turkey	0.274	Ireland – Czech Rep.	0.515
Finland – Hungary	0.324	Portugal – Turkey	0.519
Switzerland – Turkey	0.351	Czech Rep. – Greece	0.527
Ireland – Turkey	0.362	Spain – Turkey	0.553
Finland – Czech Rep.	0.364	Greece – Hungary	0.573
Netherlands – Turkey	0.369	Czech Rep. – Turkey	0.574
Germany – Turkey	0.370	Switzerland – Turkey	0.576
Average	*0.317*	*Average*	*0.528*

Table 6: Average Correlation of Each Stock Market with the Other Stock Markets

Stock Markets	Average Correlation Coefficients		
	Pre-Crash Period	Post-Crash Period	% Change
(Least Integrated, Best Portfolio Diversification Prospect)			
Turkey	0.417	0.587	+ 41 %
Czech Republic	0.459	0.652	+ 42 %
Hungary	0.462	0.712	+ 54 %
Portugal	0.509	0.717	+ 41 %
Finland	0.509	0.753	+ 48 %
Poland	0.514	0.721	+ 40 %
Austria	0.515	0.795	+ 54 %
U.S.	0.522	0.721	+ 38 %
Greece	0.538	0.601	+ 12 %
Ireland	0.562	0.656	+ 17 %

Norway	0.579	0.760	+ 31 %
Denmark	0.660	0.716	+ 8 %
Switzerland	0.666	0.764	+ 15 %
Netherlands	0.668	0.825	+ 24 %
Spain	0.669	0.758	+ 13 %
Belgium	0.670	0.770	+ 15 %
Italy	0.671	0.802	+ 20 %
U.K.	0.671	0.803	+ 20 %
Sweden	0.675	0.766	+ 13 %
Germany	0.681	0.820	+ 20 %
France	0.712	0.836	+ 17 %
(Most Integrated, Least Portfolio Diversification Opportunity)			
Average	*0.587*	*0.740*	*+ 26 %*

Under the null hypothesis of equal covariance matrices and multivariate normality, the test statistic $-2\rho \log \lambda$ has approximately a chi-squared distribution with degrees of freedom $f = \frac{1}{2} p(p+1) = 231.$ After implementing the test, we find the value of the test statistic -2ρlog λ ≈ 1041.391 (rounding to three decimal places) with p-value < 10^{-25}. Since the p-value is extremely close to zero, the test indicates a significant difference in the covariance matrices of Σ_1 and Σ_2. As noted earlier, the test results apply to the correlation matrices as well. Hence we conclude that significant changes occurred in the correlation patterns of the 21 markets after the 2008 crash.

6. Principal Components Analysis (PCA)

We use the Principal Components Analysis (PCA) methodology to compare the co-movement patterns of the twenty-one stock markets during the pre- and post-crash periods. Using Keiser's rule, statistically significant principal components with an eigen value greater than unity are extracted for analysis. We use the Varimax rotation to maximize the factor loadings of the stock markets in each principal component with similar movement patterns. The PCA technique has been used in several previous studies to study the co-movements of national stock markets [see, e.g., Philippatos et al. (1983) Meric and Meric (1989)]. A detailed discussion of the PCA technique can be found in Mardia et al. (1979) and Marascuilo and Levin (1983).

The PCA technique groups the stock markets in terms of the similarities of their movement patterns. The stock markets that are highly correlated would have high factor loadings in the same principal component. Therefore, investing in these stock markets can provide limited portfolio diversification benefit. The stock markets with high factor loadings in different principal components have low correlation. Therefore, an investor can maximize portfolio diversification benefit by investing in stock markets with the highest factor loadings in different principal components.

Every stock market would have some factor loading in each principal

component. Some stock markets might have high factor loadings in more than one principal component. It indicates that these stock markets are highly correlated with the stock markets with high factor loadings in more than one principal component. Such stock markets are not good prospects for global portfolio diversification.

Pre-Crash Period

Table 7 shows the factor loadings of the principal components for the five-year 2003-2007 pre-crash period. There are two statistically significant principal components in this period. The factor loadings of the stock markets with the highest factor loadings in each principal component are shown in bold. Some stock markets have high factor loadings in the other principal component as well. These factor loadings are shown in italics and in light font.

Table 7: Principal Components Analysis: Pre-Crash Period

Stock Markets	Principal Component #1	Principal Component #2
France	**0.921**	
Netherlands	**0.904**	
Germany	**0.903**	
Belgium	**0.855**	
Switzerland	**0.855**	
U.K.	**0.829**	
Italy	**0.827**	
Spain	**0.826**	
Sweden	**0.805**	
U.S.	**0.789**	
Denmark	**0.673**	*0.548*
Finland	**0.628**	
Ireland	**0.628**	
Portugal	**0.487**	*0.482*
Hungary		**0.835**
Czech Republic		**0.790**
Poland		**0.763**
Turkey		**0.699**
Norway	*0.441*	**0.696**
Austria	*0.503*	**0.688**
Greece	*0.505*	**0.520**
Variance Explained	*45.8 %*	*25.7 %*
Cum. Var. Explained	*45.8 %*	*71.5 %*

The first principal component explains 45.8 percent of the total variation in the original data matrix. The second principal component explains 25.7 percent of the total variation in the original data matrix. The two principal components together explain 71.5 percent of the total variation in the original data matrix. The first principal

component is dominated by the stock markets of relatively well developed European countries and the U.S. stock market. The second principal component is dominated mainly by the stock markets of relatively less developed European countries.

Investors can maximize portfolio diversification benefit by investing in the stock markets of the countries with high factor loadings in each principal component. The Danish and Portuguese stock markets which have high factor loadings in the first principal component also have high factor loadings in the second principal component. The Norwegian, Austrian, and Greek stock markets which have high factor loadings in the second principal component also have high factor loadings in the first principal component. Therefore, these stock markets are not good prospects for portfolio diversification.

Post-Crash period

Table 8 shows the factor loadings of the stock markets for the post-crash period. There is only one statistically significant principal component in this period. This indicates that all stock markets are highly correlated and they are clustered in the same principal component in this period (i.e., there are no stock markets with significantly different movement patterns from the other stock markets to justify the creation of a separate statistically significant principal component). The principal component explains 75.7 percent of the total variation in the original data matrix.

Table 8: Principal Components Analysis: Post-Crash Period

Stock Markets	Principal Component #1
France	**0.976**
Netherlands	**0.963**
Germany	**0.957**
Italy	**0.938**
U.K.	**0.932**
Austria	**0.929**
Belgium	**0.902**
Sweden	**0.898**
Switzerland	**0.896**
Norway	**0.891**
Spain	**0.889**
Finland	**0.884**
U.S.	**0.849**
Poland	**0.845**
Portugal	**0.843**
Denmark	**0.841**
Hungary	**0.835**
Ireland	**0.770**
Czech Republic	**0.768**
Greece	**0.710**
Turkey	**0.693**
Variance Explained	*75.7 %*

The movements of the French, Dutch, German, Italian, and U.K. stock markets are highly correlated and they have the highest factor loadings in the principal component. The Irish, Czech, Greek, and Turkish stock markets are relatively less correlated with the other stock markets. However, diversifying into these stock markets can provide only a non-significant portfolio diversification benefit to investors.

7. Summary and Conclusions

Empirical studies demonstrate that correlation between the world's stock markets increase and the benefits of global portfolio diversification decrease after stock market crashes. 1987 and 2008 crashes are the most important global stock market crashes since the 1929 Great Depression. Although the effects of the 1987 crash on the co-movements of the world's stock markets have been studied extensively, the effects of the 2008 stock market crash have not been studied sufficiently. We study this issue in this paper by comparing the co-movement patterns of the U.S. and twenty European stock markets in the 2003-2007 five-year pre-crash period and the 2009-2013 five-year post-crash period.

Our findings indicate that the co-movements of the twenty-one stock markets changed significantly after the 2008 stock market crash. The covariance matrix of the markets is significantly different in the post-crash period compared with the pre-crash period; the stock markets are more highly correlated after the 2008 crash than before the crash. Our principal components analysis results show that there is only one statistically significant principal component in the post-crash period compared with two statistically significant principal components in the pre-crash period. This implies a closer co-movement pattern between the markets after the crash. These results indicate that portfolio diversification opportunities in the U.S and European stock markets decreased significantly after the 2008 crash.

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