The 2011 Japanese earthquake, tsunami and nuclear crisis: evidence of contagion from international financial markets

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Abstract

Purpose – Natural disasters may inflict significant damage upon international financial markets. The purpose of this study is to investigate if any contagion effect occurred in the immediate aftermath of the Japanese earthquake, tsunami and subsequent nuclear crisis.

Design/methodology/approach – Using 33 international stock indices and exchange rates, this paper uses heteroscedasticity biases based on correlation coefficients to examine if any contagion occurred across financial markets after the March 11, 2011 Japanese earthquake, tsunami and nuclear crisis. The sample period is partitioned into two sections: the 12-month pre-earthquake period (March 11, 2010 to March 10, 2011) and the 2-month post-earthquake period (March 11, 2011 to May 10, 2011). While the stability period is defined as the pre-earthquake period, the turbulent (turmoil) period is defined as the post-earthquake period. In a bid to ensure robustness of our findings, the turmoil period is further partitioned into two equal sections: the 1-month (short-term) post-earthquake period (March 11, 2011 to April 10, 2011), and the 2-month (medium-term) post-earthquake (March 11, 2011 to May 10, 2011).

Findings – Findings reveal that, while no sampled foreign exchange markets suffered from contagion, stock markets of Taiwan, Bahrain, Saudi Arabia and South Africa witnessed a contagion effect.

Practical implications – Our results have two paramount implications. Firstly, we have confirmed existing consensus that in the face of natural crises that could take an international scale, emerging markets are contagiously affected for the most part. Secondly, the empirical evidence also suggest that international financial market transmissions not only occur during financial crisis; natural disaster effects should not be undermined.

Originality/value – This paper has shown that the correlation structure of international financial markets are also affected by high profile natural disasters.

JEL Classification: G10; G15; F30
Keywords: Japanese Earthquake; Contagion; International Financial Markets

1. Motivation

Natural disasters have inflicted serious damage on human life, property and economy. Though many earthquakes occur worldwide on an annual basis and impact all walks of life in one way or the other, collateral effects resulting from such natural disasters could be quite detrimental financially and economically. The recent Japanese earthquake resulted in collateral damage that makes the disaster particularly significant. On March 11, 2011, a 9.0 magnitude undersea mega thrust earthquake hit Tohoku in Japan. This powerful shock triggered a tsunami that struck coastlines across the east of the country, leaving thousands dead and damaging considerable property. But what appears to have left analysts startled and concerned over the consequences of this earthquake is the nuclear disaster resulting there-from. Recently classified as a level-seven event on the International Nuclear Event Scale, the Fukushima nuclear incident now poses a risk equal to the worst nuclear power plant accident in history (Chernobyl disaster). With much uncertainty over how the crisis would be managed, it is imperative to investigate how international financial markets have so far reacted.

Therefore the goal of this paper is to examine whether any contagion effect has occurred two months after the Japanese earthquake, tsunami and worst nuclear crisis since Chernobyl. In other words, we seek to provide evidence as to whether such a disaster has increased the interdependence among financial assets in different countries. The remainder of the paper is organized as follows. Sections 2 examines related literature. Data and methodology are presented and outlined respectively in Section 3. Empirical analysis is covered in Section 4. We discuss results in Section 5. Section 6 concludes.

2. Related literature

2.1 Effects of financial market integration

Financial integration is widely believed to improve capital allocation efficiency and diversify risks (Demyanyk and Volosovych, 2008; Coulibaly, 2009; Kose et al., 2011). However, the recent global financial crisis deemed as the worst since the Great Depression has left many analysts concerned about the contagion effects of globalization. A great body of literature has been dedicated to the potential benefits of financial integration.

With respect to Kose et al. (2011), financial globalization in theory should facilitate efficient allocation of capital and improve international risk sharing. They further profess that benefits are much greater for developing countries because they are relatively scarce in capital and rich in labor availability. According to them, access to foreign capital should enable them grow faster via new sources of investment. On a positive note of financial globalization, Kose et al. stress that since developing countries have more volatile output growth than advanced industrial economies, their potential welfare gains from international risk sharing are much greater. It is important to note an important finding of theirs: with certain identifiable thresholds in variables such as financial depth and institutional quality, the cost-benefit trade-off from financial openness improves significantly once the threshold conditions are met. Much earlier, Demyanyk and Volosovych (2008) analyzed the benefits of financial integration resulting from international risk sharing among 25 European Union (EU) countries. In their case for diversification of risk across EU member states, they posit that if risks are fully shared, the 10 new members joining the EU should have higher gains than the long standing 15 members. It may be interesting to note South Africa as one of the most striking examples of the cost and benefits of financial integration. As a country that experienced financial autarky due to the

embargo imposed in 1985 and removed in 1993, Coulibaly (2009) found a significant decrease in the rates of investment, capital and output during the embargo period as compared to pre-embargo and post-embargo periods. By the same token South Africa might have been immune to contagion from a global financial meltdown during the embargo period.

It follows that countries in relative financial autarky are less exposed to international shocks. While the prime advantage of financial integration is risk diversification, paradoxically increased financial globalization can reduce the scope for risk diversification as integrated markets tend to be more correlated and highly interdependent. On another negative note, Kose et al. (2011) stress that a country may stand to reap the benefits of financial integration if certain threshold factors like financial depth and institutional quality are met. This stance is shared by Schmukler (2004) who has underlined the importance of sound financial fundamentals and strong macroeconomic institutions; the absence of which will decrease the effectiveness of crises management and increase the probability of crises and contagion.

2.2 Linkages among natural disasters, globalization and crises

In the first part of this literature review, we present several benefits of financial integration as well as potential costs. As such , occurrences or crises in one country often due to domestic factors (human or natural) could be propagated to other countries through channels of globalization(trade or financial links for instance). There are four main routes via which natural disasters like the Japanese turmoil could lead to crises at a global level.

On a first count, as stressed by Schmukler (2004), when a country's financial system is more free, it becomes an object of market discipline exercised by both foreign and domestic investors. As such reactions to unsound fundamentals resulting from natural disasters are not

only the concern of domestic investors as in closed economies. If the prospects for resolving the disaster are unclear, asymmetric information may lead investors to make irrational decisions that could result in a crisis depending on the degree of financial integration.

On a second note, international financial market imperfections could arise from a natural disaster, especially herding behavior, speculative attacks, irrational responses...etc. Thus, regardless of market fundamentals, investors could speculate against a currency in the wake of a natural calamity if they deem the exchange rate unsustainable, which could lead to self-fulfilling balance-of-payments. This thesis presented by Obstfeld (1986) has been supported by Schmukler (2004) and more recently Asongu (2011a,b).

Thirdly, even in the presence of sound fundamentals and absence of imperfections in the international capital market (after a natural disaster), crises might develop due to external factors (Schmukler, 2004) such as determinants of capital flows (Calvo et al., 1996) and foreign interest rates (Frankel and Rose, 1996). For example, if the country is foreign capital dependent, shifts in foreign capital after a natural calamity could create additional financial issues and economic downturns. As pointed out by Frankel and Rose (1996), foreign interest rates could play an important role in determining the likelihood of financial crises in developing countries.

Last but not the least, according to Schmukler (2004) natural disasters could lead to crisis by contagion, notably through shocks by real links, financial links and herding behavior or unexplained high correlations. Our focus on this Japanese earthquake will rotate around this fourth example; the definition and elucidation of which are worthwhile.

2.3 Definitions and channels of contagion

2.3.1 Definitions of contagion

There is yet no established consensus on the definition of contagion by economists. However according to the World Bank there are three main definitions of contagion. First, from a broad prism the phenomenon could be seen with the general process of shock transmission across countries. This definition takes account of both negative and positive spillovers. Secondly, contagion could be synonymous with the propagation of shocks between two countries in excess of what should be expected with respect to existing fundamentals after considering co-movements triggered by common shocks. This second definition is somehow restrictive as it presupposes the mastery of what constitutes the underlying fundamentals, without which an assessment of excess co-movements is impossible. The third and more restrictive definition considers the phenomenon as the change in transmission mechanisms that occur during the crisis period and is assessed by a significant increase in cross-market correlations.

With respect to this study, we shall limit ourselves to the third definition of contagion because: (1) our study aims to investigate only a crisis-period in the Japanese financial market (as opposed to the first definition); and (2) we have no mastery of what constitutes underlying fundamentals of co-movements we are about to investigate.

From an empirical standpoint, Forbes and Rigobon (2002) first proposed a methodology for the third definition. They view contagion as a significant increase in market co-movements after a shock has occurred in one country. Owing to this conception, the condition for contagion is a significant increase in co-movements as a result of a shock in one market (considered the base criterion). It follows that if two markets display a high degree of co-movement during the stability period, even if they are highly correlated during a crisis, but if the difference in

correlation is insignificant, contagion has not occurred. Thus in the absence of a significant increase in correlation during the crisis period, the term 'interdependence' is employed to appraise the situation between the two markets.

2.3.2 Channels of contagion

In accordance with Schmukler (2004), three main channels of contagion have been identified in the literature. (1) Through real links which are often tied to trade links. As an example, if we consider two countries trading together and competing in the same external market, a devaluation of the exchange rate of one country diminishes the other country's competitive advantage. In an attempt to rebalance its external sectors, the losing country would seek to depreciate/devaluate its own currency. (2) Via financial channels especially when two economies are connected through the international financial system. If we consider a leveraged institution facing margin calls as an example, and if the value of the collateral falls due to a negative shock in a given country, the institution would be poised to sell some of its holdings in countries not yet affected by the shock in an attempt to mitigate its initial stock. This response may give rise to ripples of shocks that could engender contagion. (3) Lastly, as a result of herding behavior or panic resulting from asymmetric information, a financial market might transmit shocks across other markets.

2.4 Measuring contagion

Quite a number of methods have been suggested in the literature for measuring the spread of international shocks across countries. Among these, the most widely applied are cross-market correlation coefficient measures (Lee et al., 2007; Collins and Biekpe, 2003; Forbes and

Rigobon, 2002; King and Wadhwani, 1990), volatility analysis based on ARCH and GARCH models (King et al., 1994), cross-market co-integration vectors changing techniques (Kanas, 1998) and direct estimation of specific transmission mechanisms(Forbes, 2000). Within the framework of this study, we shall adopt Forbes and Rigobon (2002) in the context of Lee et al. (2007).

3. Data and Methodology

3.1 Data

As we have earlier emphasized, we aim to investigate the correlations among returns of the Japanese daily stock index (exchange rate) and 33 other international stock indexes (exchange rates) returns. Adopting the Japanese equity and foreign exchange markets as the base criterion, we investigate if co-movements among national stock and foreign exchange markets increased significantly after the major earthquake, tsunami and nuclear disaster. The sample period is partitioned into two sections: the 12-month pre-earthquake period (March 11, 2010 to March 10, 2011) and the 2-month post-earthquake period (March 11, 2011 to May 10, 2011)[1]. While the stability period is defined as the pre-earthquake period, the turbulent (turmoil) period is defined as the post-earthquake period. In a bid to ensure robustness of our findings, the turmoil period is further partitioned into two equal sections: the 1-month (short-term) post-earthquake period (March 11, 2011 to April 10, 2011), and the 2-month (medium-term) post-earthquake (March 11, 2011 to May 10, 2011). The number of days are respectively 365, 31, 62 days for the stable, short-term turmoil and medium-term turmoil periods. Data used in the study is obtained from Bloomberg's database. In the computation of stock returns, last values are carried over for

[1] Differences in pre-earthquake and post-earthquake sample periods are in line with Collins and Biekpe (2003); Lee et al.(2007) and Asongu(2011ab).

non-trading days. The US dollar is used as the common "x" unit of foreign currency for each unit of national/regional currency in the computation of exchange rate returns. Our use of local currency index return is in line with Forbes and Rigobon (2002) who have shown that using dollar or local indices will produce similar results.

3.2 Methodology

Borrowing from Forbes and Rigobon (2002), contagion is a significant increase in market co-movements after a shock has occurred in one country.

The coefficient of correlation is defined as:

$$\rho = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \qquad (1)$$

Where: 'x' represents the base criterion and 'y' an international market. This correlation coefficient is adjusted in the following manner to take account of heteroscedasticity:

$$\rho^* = \frac{\rho}{\sqrt{1+\delta[1-(\rho)^2]}} \qquad (2)$$

Where:

$$\delta = \frac{\sigma_{xx}^{h}}{\sigma_{xx}^{l}} - 1$$

It measures the change in high-period volatility against volatility in the low-period. While the crisis interval is used as the high volatility period, the tranquil or stable-period represents the low volatility period. Contagion is eventually measured as the significant increase of adjusted correlation coefficients in time-varying turmoil periods against the stability period.

Borrowing from Lee et al (2007), the following hypotheses are tested:

$$H_o : \rho_t - \rho_s \leq 0 \ \textit{versus} \ H_1 : \rho_t - \rho_s > 0$$

Where, ρt is the adjusted correlation coefficient during the turmoil period and ρs the adjusted correlation coefficient for the stable period. A comparison of the difference in correlation between the stable and crisis periods is then carried-out. The null hypothesis (*H0*) is the hypothesis of no contagion while *H1* is the alternative hypothesis for the presence of contagion. Fisher's Z transformations of correlation coefficients are used to test pair-wise cross-country significance. This Fisher's Z-transformations change standard coefficients to normally distributed Z variables. Therefore, before hypothesis testing, ρ values must be converted to Zr values.

$$H_o : \rho_t - \rho_s \leq 0 \Rightarrow H_o : Z_{rt} - Z_{rs} \leq 0$$

$$H_1 : \rho_t - \rho_s > 0 \Rightarrow H_1 : Z_{rt} - Z_{rs} > 0$$

Where:

$$Z_{rt} = \frac{1}{2}\ln\left(\frac{1+\rho_t}{1-\rho_t}\right)$$

$$Z_{rs} = \frac{1}{2}\ln\left(\frac{1+\rho_s}{1-\rho_s}\right)$$

$$Z = \frac{Z_{rt} - Z_{rs}}{\sqrt{(1/(n_t - 3)) + (1/(n_s - 3))}}$$

4. Empirical Results

4.1 Contagion effect in international stock indexes returns after earthquake

Table 1 shows the conditional (unadjusted) correlation coefficients of international stock indexes for the 2011 Japanese Tsunami. Cross-market correlations of stock index returns are compared before and after the earthquake of March 11, 2011. With the exceptions of China, Taiwan, New Zealand, Argentina, Bahrain, Egypt, Saudi Arabia and South Africa; cross-market correlations between Japan and most countries in the sample during stable period are higher than those during medium-term turmoil period. For the short-run interval, correlations are strengthened for China, Hong Kong, Taiwan, South Korea, Australia, New Zealand, Argentina, Germany, Bahrain, South Africa and Saudi Arabia. There is significant evidence of contagion in Taiwan, Bahrain, Saudi Arabia and South Africa for the short-term turmoil period and only in Bahrain and Saudi Arabia for the medium-term turmoil interval. Comparatively, for the most part volatilities of most countries during the stable period are higher than those during turmoil periods (short and medium terms).

Unconditional correlation coefficients are presented in Table 2. These adjusted correlations are higher that their unadjusted counterparts in table 1. Results of Table 1 are substantiated by those of Table 2.

4.2 Contagion effect in international exchange rates returns after earthquake

Findings in Table 3 present exchange rate conditional (unadjusted) correlation coefficients. Cross-market correlations during turmoil periods are higher than those during the stable period. Strengthened cross-market correlations with insignificant evidence of contagion are noticeable for Thai Baht (THB), Argentinian Peso (ARS), Egyptian Pound (EGP), and Qatari Riyal (QAR) for the short-term turmoil period. With regard to the medium-term, the Chinese

Yuan (RMB), Canadian Dollar (CAD), Egyptian pound (EGP), Qatari Riyal (QAR) and Emirati dirham (AED) also witnessed insignificant stronger co-movements with the Japanese Yen (JPY). Adjusted results from Table 4 confirm those in Table 3. In summary, no national/regional exchange market is found to have suffered from contagion two months in the aftermath of the Japanese earthquake and ensuing collateral disasters.

Table 1: International stock indices returns conditional (unadjusted) correlation coefficients in 2011 Japanese earthquake

		Full period		Stable Period		Short-term turmoil period				Medium-term turmoil period			
Regions	Countries	ρ	σ	ρ	σ	ρ	σ	Z-test	Co	ρ	σ	Z-test	Co
South Asia and South-East Asia	India	0.288	0.009	0.343	0.009	0.247	0.009	-0.538	N	0.171	0.009	-1.321	N
	Malaysia	0.372	0.005	0.405	0.005	0.392	0.005	-0.080	N	0.348	0.005	-0.474	N
	Philippines	0.317	0.009	0.357	0.009	0.295	0.009	-0.353	N	0.266	0.008	-0.715	N
	Singapore	n.a	0.000	n.a	0.000	n.a	0.000	n.a	n.a	n.a	0.000	n.a	n.a
	Thailand	0.308	0.009	0.361	0.010	0.278	0.008	-0.470	N	0.209	0.008	-1.180	N
East Asia and North-East Asia	China	0.283	0.011	0.309	0.012	0.477	0.007	1.022	N	0.321	0.007	0.100	N
	Hong Kong	0.510	0.009	0.542	0.009	0.574	0.009	0.240	N	0.525	0.008	-0.166	N
	Taiwan	0.587	0.008	0.591	0.008	0.781	0.008	**1.881***	Y	0.694	0.008	1.247	N
	South Korea	0.575	0.008	0.606	0.008	0.660	0.008	0.458	N	0.566	0.008	-0.437	N
Australasia	Australia	-0.004	0.008	0.000	0.008	0.073	0.007	0.373	N	-0.021	0.007	-0.147	N
	New Zealand	0.440	0.004	0.459	0.004	0.609	0.004	1.080	N	0.515	0.004	0.525	N
North America	Canada	-0.055	0.197	-0.013	0.208	-0.441	0.125	-2.348	N	-0.343	0.110	-2.455	N
	U.S.A	0.176	0.012	0.217	0.013	0.054	0.008	-0.848	N	0.074	0.007	-1.041	N
	Mexico	0.159	0.007	0.208	0.007	0.048	0.006	-0.831	N	0.027	0.006	-1.310	N
South America	Argentina	0.174	0.012	0.163	0.013	0.312	0.011	0.807	N	0.269	0.010	0.795	N
	Brazil	0.076	0.010	0.120	0.010	-0.033	0.006	-0.783	N	-0.069	0.008	-1.351	N
	Chile	0.117	0.007	0.178	0.007	-0.086	0.008	-1.357	N	-0.035	0.007	-1.532	N
Europe	France	0.321	0.012	0.366	0.012	0.253	0.011	-0.639	N	0.254	0.010	-0.883	N
	Poland	0.218	0.008	0.287	0.008	-0.045	0.006	-1.735	N	0.013	0.006	-2.014	N
	Germany	0.325	0.009	0.366	0.009	0.350	0.012	0.083	N	0.334	0.011	-0.012	N
	Italy	0.248	0.013	0.292	0.013	0.142	0.009	-0.806	N	0.169	0.009	-0.928	N
	Holland	0.332	0.010	0.378	0.010	0.296	0.008	-0.473	N	0.271	0.008	-0.851	N
	Spain	0.193	0.015	0.255	0.016	-0.116	0.009	-1.923	N	-0.001	0.009	-1.860	N
	U.K	0.292	0.009	0.361	0.009	0.135	0.008	-1.234	N	0.129	0.008	-1.764	N
Middle East and Africa	**Bahrain**	0.006	0.005	-0.050	0.005	0.290	0.006	**1.774***	Y	0.207	0.005	**1.850***	Y
	Egypt	0.116	0.013	0.104	0.011	0.098	0.028	-0.027	N	0.131	0.022	0.198	N
	Jordan	-0.035	0.005	-0.020	0.005	-0.101	0.006	-0.413	N	-0.097	0.005	-0.554	N
	Kuwait	-0.073	0.005	-0.026	0.005	-0.298	0.006	-1.431	N	-0.256	0.004	-1.679	N
	Qatar	0.019	0.009	0.046	0.009	-0.080	0.009	-0.641	N	-0.064	0.008	-0.785	N
	Saudi Arabia	0.182	0.011	0.117	0.011	0.493	0.013	**2.154****	Y	0.457	0.010	**2.678*****	Y
	UAE	0.080	0.006	0.109	0.006	-0.055	0.006	-0.836	N	0.010	0.005	-0.706	N
	South Africa	0.348	0.009	0.343	0.009	0.634	0.008	**1.994****	Y	0.434	0.009	0.766	N
Other	Russia	0.290	0.012	0.378	0.012	0.007	0.010	-1.992	N	0.069	0.012	-2.338	N

Note 1: *, **, ***: statistical significance at 10%, 5% and 1% respectively.

Note 2: The table shows conditional (unadjusted) cross-market correlation coefficients (ρ) and standard deviations (σ) for Japan and other stock indexes. The test statistics are obtained from Fisher Z transformations. The stable period is defined as the 12-month pre-earthquake period (March 11, 2010 to March 10, 2011). The short-term turmoil period is defined as the 1-month post-earthquake period (March 11, 2011 to April 10, 2011). The medium-term turmoil period is defined as the 2-month post-earthquake period (March 11, 2011 to May 10, 2011). The full period is the stable period plus the medium-term turmoil period. Co: contagion .While "Y" denotes that the test statistics is greater than the critical value and contagion occurred, "N" indicates that the test statistics was less or equal to the critical value and no contagion occurred.

Note 3: Correlation coefficients are unadjusted for heteroscedasticity.

Table 2: International stock indices returns unconditional (adjusted) correlation coefficients in 2011 Japanese earthquake

		Full period		Stable Period		Short-term turmoil period				Medium-term turmoil period			
Regions	Countries	ρ	σ	ρ*stp	ρ*mtp	ρ*	δ	Z-test	Co	ρ*	δ	Z-test	Co
South Asia and South-East Asia	India	0.288	0.009	0.430	0.445	0.315	-0.017	-0.679	N	0.229	0.032	-1.745	N
	Malaysia	0.372	0.005	0.500	0.516	0.485	-0.077	-0.099	N	0.451	-0.111	-0.609	N
	Philippines	0.317	0.009	0.445	0.460	0.373	0.007	-0.443	N	0.351	-0.143	-0.933	N
	Singapore	n.a	0.000	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	Thailand	0.308	0.009	0.450	0.465	0.352	-0.165	-0.591	N	0.279	-0.155	-1.549	N
East Asia and North-East Asia	China	0.283	0.011	0.389	0.403	0.577	-0.433	1.262	N	0.418	-0.387	0.130	N
	Hong Kong	0.510	0.009	0.642	0.658	0.674	0.048	0.283	N	0.642	-0.106	-0.203	N
	Taiwan	0.587	0.008	0.690	0.706	0.852	0.047	**2.119****	Y	0.794	-0.043	1.458	N
	South Korea	0.575	0.008	0.704	0.719	0.753	0.016	0.528	N	0.682	0.092	-0.523	N
Australasia	Australia	-0.004	0.008	0.000	0.000	0.095	-0.706	0.485	N	-0.028	-0.120	-0.199	N
	New Zealand	0.440	0.004	0.558	0.574	0.707	-0.119	1.283	N	0.632	-0.172	0.651	N
North America	Canada	-0.055	0.197	-0.017	-0.018	-0.539	-0.401	-2.985	N	-0.445	-0.473	-3.277	N
	U.S.A	0.176	0.012	0.278	0.289	0.070	-0.410	-1.096	N	0.100	-0.458	-1.401	N
	Mexico	0.159	0.007	0.267	0.278	0.063	-0.174	-1.074	N	0.037	-0.118	-1.767	N
South America	Argentina	0.174	0.012	0.210	0.219	0.393	-0.139	1.029	N	0.355	-0.198	1.059	N
	Brazil	0.076	0.010	0.155	0.162	-0.043	-0.381	-1.018	N	-0.094	-0.228	-1.833	N
	Chile	0.117	0.007	0.229	0.238	-0.112	0.215	-1.761	N	-0.048	0.038	-2.073	N
Europe	France	0.321	0.012	0.456	0.471	0.322	-0.124	-0.805	N	0.336	-0.188	-1.153	N
	Poland	0.218	0.008	0.364	0.377	-0.058	-0.295	-2.240	N	0.017	-0.295	-2.702	N
	Germany	0.325	0.009	0.421	0.436	0.437	0.255	0.104	N	0.434	0.142	-0.015	N
	Italy	0.248	0.013	0.369	0.383	0.183	-0.314	-1.032	N	0.227	-0.306	-1.232	N
	Holland	0.332	0.010	0.469	0.485	0.374	-0.209	-0.593	N	0.358	-0.242	-1.108	N
	Spain	0.193	0.015	0.324	0.337	-0.151	-0.406	-2.489	N	-0.001	-0.443	-2.504	N
	U.K	0.292	0.009	0.450	0.465	0.175	-0.152	-1.571	N	0.175	-0.120	-2.333	N
Middle East and Africa	**Bahrain**	0.006	0.005	-0.065	-0.067	0.367	0.022	**2.290****	Y	0.276	-0.156	**2.501****	Y
	Egypt	0.116	0.013	0.134	0.140	0.127	1.605	-0.036	N	0.177	0.991	0.268	N
	Jordan	-0.035	0.005	-0.026	-0.027	-0.131	0.077	-0.537	N	-0.132	-0.159	-0.752	N
	Kuwait	-0.073	0.005	-0.034	-0.036	-0.376	0.088	-1.841	N	-0.339	-0.157	-2.257	N
	Qatar	0.019	0.009	0.059	0.062	-0.104	0.037	-0.834	N	-0.087	-0.133	-1.066	N
	Saudi Arabia	0.182	0.011	0.152	0.158	0.594	0.170	**2.705*****	Y	0.572	-0.111	**3.502*****	Y
	UAE	0.080	0.006	0.141	0.147	-0.071	0.012	-1.087	N	0.014	-0.085	-0.957	N
	South Africa	0.348	0.009	0.429	0.444	0.730	-0.136	**2.394****	Y	0.548	-0.036	0.980	N
Other	Russia	0.290	0.012	0.469	0.485	0.009	-0.176	-2.550	N	0.094	-0.006	-3.100	N

Note 1: *, **, ***: statistical significance at 10%, 5% and 1% respectively.

Note 2: The table shows conditional (unadjusted) cross-market correlation coefficients (ρ) , adjuster for heteroscedasticity (δ) and standard deviations (σ) for Japan and other stock indexes. The test statistics are obtained from Fisher Z transformations. The stable period is defined as the 12-month pre-earthquake period (March 11, 2010 to March 10, 2011). The short-term turmoil period is defined as the 1-month post-earthquake period (March 11, 2011 to April 10, 2011). The medium-term turmoil period is defined as the 2-month post-earthquake period (March 11, 2011 to May 10, 2011). The full period is the stable period plus the medium-term turmoil period. Co: contagion. While "Y" denotes that the test statistics is greater than the critical value and contagion occurred, "N" indicates that the test statistics was less or equal to the critical value and no contagion occurred. ρ*stp, ρ*mtp, denote adjusted correlation coefficients for the short and medium term periods respectively. δ: correlation coefficient adjuster.

Note 3: Correlation coefficients are adjusted for heteroscedasticity using Equation 2.

Table 3: International exchange rates returns conditional (unadjusted) correlation coefficients in 2011 Japanese earthquake

		Full period		Stable Period		Short-term turmoil period				Medium-term turmoil period			
Regions	Countries	ρ	σ	ρ	σ	ρ	σ	Z-test	Co	ρ	σ	Z-test	Co
	India	-0.136	0.004	-0.130	0.005	-0.282	0.002	-0.807	N	-0.207	0.002	-0.560	N
South Asia	Malaysia	-0.197	0.004	-0.191	0.005	-0.332	0.002	-0.773	N	-0.267	0.003	-0.570	N
and South-	Philippines	-0.129	0.004	-0.128	0.005	-0.439	0.003	-1.746	N	-0.143	0.003	-0.105	N
East Asia	Singapore	-0.029	0.003	-0.015	0.004	-0.197	0.003	-0.940	N	-0.109	0.003	-0.674	N
	Thailand	0.061	0.002	0.066	0.004	0.235	0.002	0.885	N	0.023	0.002	-0.307	N
East Asia	China	0.030	0.001	0.018	0.004	-0.090	0.001	-0.551	N	0.085	0.001	0.482	N
and North-	Hong Kong	-0.049	0.000	-0.020	0.004	-0.223	0.000	-1.049	N	-0.225	0.000	-1.481	N
East Asia	Taiwan	-0.104	0.003	-0.080	0.004	-0.400	0.002	-1.748	N	-0.251	0.002	-1.256	N
	South Korea	-0.242	0.007	-0.226	0.007	-0.500	0.005	-1.630	N	-0.415	0.004	-1.508	N
Australasia	Australia	-0.080	0.007	-0.042	0.007	-0.428	0.006	-2.120	N	-0.325	0.006	-2.099	N
	New Zealand	-0.031	0.007	0.035	0.007	-0.612	0.007	-3.812	N	-0.419	0.006	-3.432	N
North	Canada	-0.272	0.006	-0.275	0.006	-0.390	0.004	-0.662	N	-0.274	0.004	0.010	N
America	Mexico	-0.338	0.005	-0.339	0.006	-0.521	0.003	-1.151	N	-0.385	0.004	-0.378	N
South	Argentina	-0.030	0.001	-0.026	0.001	-0.024	0.001	0.010	N	-0.059	0.001	-0.237	N
America	Brazil	-0.205	0.006	-0.181	0.006	-0.415	0.005	-1.316	N	-0.356	0.006	-1.347	N
	Chile	0.012	0.005	0.046	0.006	-0.281	0.004	-1.707	N	-0.234	0.004	-2.028	N
Europe	Euro	0.166	0.006	0.211	0.006	-0.204	0.004	-2.151	N	-0.079	0.006	-2.094	N
	U.K	0.043	0.005	0.073	0.005	-0.211	0.005	-1.467	N	-0.147	0.004	-1.576	N
	Bahrain	-0.021	0.006	-0.014	0.000	-0.029	0.000	-0.077	N	-0.043	0.000	-0.208	N
	Egypt	0.037	0.001	0.022	0.001	0.133	0.001	0.566	N	0.194	0.001	1.239	N
Middle	Jordan	-0.026	0.001	-0.024	0.001	-0.131	0.000	-0.548	N	-0.036	0.000	-0.088	N
East and	Kuwait	0.247	0.001	0.258	0.001	0.182	0.001	-0.408	N	0.187	0.001	-0.533	N
Africa	Qatar	0.037	0.000	0.029	0.000	0.211	0.000	0.994	N	0.178	0.000	1.072	N
	Saudi Arabia	-0.027	0.000	0.005	0.000	-0.334	0.000	-1.795	N	-0.194	0.000	-1.431	N
	UAE	-0.086	0.000	-0.094	0.001	-0.211	0.005	n.a	n.a	-0.037	0.000	0.406	N
	South Africa	-0.130	0.007	-0.074	0.007	-0.601	0.007	-3.170	N	-0.448	0.007	-2.906	N
Other	Russia	-0.140	0.004	-0.132	0.005	-0.377	0.003	-1.347	N	-0.211	0.004	-0.580	N

Note 1: *, **, ***: statistical significance at 10%, 5% and 1% respectively. n.a: the presence of zero exchange rate return for all periods of the series.

Note 2: The table shows conditional (unadjusted) cross-market correlation coefficients (ρ) and standard deviations (σ) for Japan and other stock indexes. The test statistics are obtained from Fisher Z transformations. The stable period is defined as the 12-month pre-earthquake period (March 11, 2010 to March 10, 2011). The short-term turmoil period is defined as the 1-month post-earthquake period (March 11, 2011 to April 10, 2011). The medium-term turmoil period is defined as the 2-month post-earthquake period (March 11, 2011 to May 10, 2011). The full period is the stable period plus the medium-term turmoil period. Co: contagion .While "Y" denotes that the test statistics is greater than the critical value and contagion occurred, "N" indicates that the test statistics was less or equal to the critical value and no contagion occurred.

Note 3: Correlation coefficients are unadjusted for heteroscedasticity.

Table 4: International exchange rates returns unconditional (adjusted) correlation coefficients in 2011 Japanese earthquake

		Full period		Stable Period		Short-term turmoil period				Medium-term turmoil period			
Regions	Countries	ρ	σ	ρ*stp	ρ*mtp	ρ*	δ	Z-test	Co	ρ*	δ	Z-test	Co
	India	-0.136	0.004	-0.181	-0.168	-0.379	-0.487	-1.104	N	-0.265	-0.408	-0.721	N
South Asia	Malaysia	-0.197	0.004	-0.262	-0.245	-0.441	-0.510	-1.045	N	-0.339	-0.356	-0.728	N
and South-	Philippines	-0.129	0.004	-0.178	-0.166	-0.564	-0.267	-2.341	N	-0.184	-0.281	-0.136	N
East Asia	Singapore	-0.029	0.003	-0.021	-0.020	-0.270	-0.154	-1.304	N	-0.141	-0.088	-0.874	N
	Thailand	0.061	0.002	0.092	0.086	0.320	-0.282	1.222	N	0.030	-0.194	-0.399	N
East Asia	China	0.030	0.001	0.024	0.023	-0.126	-0.142	-0.769	N	0.110	0.135	0.626	N
and North-	Hong Kong	-0.049	0.000	-0.029	-0.027	-0.304	0.072	-1.453	N	-0.287	-0.099	-1.913	N
East Asia	Taiwan	-0.104	0.003	-0.112	-0.104	-0.520	-0.065	-2.367	N	-0.320	-0.085	-1.617	N
	South Korea	-0.242	0.007	-0.308	-0.289	-0.628	-0.322	-2.138	N	-0.510	-0.375	-1.892	N
Australasia	Australia	-0.080	0.007	-0.059	-0.055	-0.552	-0.096	-2.868	N	-0.407	-0.142	-2.690	N
	New Zealand	-0.031	0.007	0.049	0.046	-0.734	-0.051	-5.032	N	-0.515	-0.078	-4.378	N
North	Canada	-0.272	0.006	-0.371	-0.349	-0.509	-0.275	-0.878	N	-0.347	-0.260	0.013	N
America	Mexico	-0.338	0.005	-0.449	-0.424	-0.649	-0.407	-1.480	N	-0.476	-0.350	-0.470	N
South	Argentina	-0.030	0.001	-0.261	-0.033	-0.033	-0.261	0.013	N	-0.077	-0.067	-0.308	N
America	Brazil	-0.205	0.006	-0.246	-0.233	-0.537	-0.231	-1.761	N	-0.444	-0.072	-1.708	N
	Chile	0.012	0.005	0.064	-0.072	-0.378	-0.253	-2.359	N	-0.444	-0.233	-2.622	N
Europe	Euro	0.166	0.006	0.289	0.271	-0.280	-0.231	-2.983	N	-0.103	-0.001	-2.712	N
	U.K	0.043	0.005	0.102	0.095	-0.289	-0.074	-2.038	N	-0.190	-0.150	-2.045	N
	Bahrain	-0.021	0.006	-0.019	-0.018	-0.041	9.215	-0.107	N	-0.056	6.189	-0.271	N
	Egypt	0.037	0.001	0.031	0.029	0.184	-0.400	0.788	N	0.249	-0.496	1.603	N
Middle	Jordan	-0.026	0.001	-0.034	-0.031	-0.181	-0.560	-0.763	N	-0.047	-0.495	-0.114	N
East and	Kuwait	0.247	0.001	0.349	0.328	0.250	-0.419	-0.557	N	0.240	-0.338	-0.681	N
Africa	Qatar	0.037	0.000	0.041	0.038	0.289	-0.500	1.308	N	0.229	-0.649	1.387	N
	Saudi Arabia	-0.027	0.000	0.006	0.006	-0.444	0.079	-2.464	N	-0.249	0.025	-1.852	N
	UAE	-0.086	0.000	-0.131	-0.122	n.a	-1.000	n.a	n.a	-0.048	-0.816	0.526	N
	South Africa	-0.130	0.007	-0.103	-0.095	-0.725	0.003	-2.038	N	-0.545	-0.041	-3.676	N
Other	Russia	-0.140	0.004	-0.183	-0.170	-0.494	-0.316	-1.821	N	-0.270	-0.187	-0.746	N

Note 1: *, **, ***: statistical significance at 10%, 5% and 1% respectively.

Note 2: The table shows conditional (unadjusted) cross-market correlation coefficients (ρ), adjuster for heteroscedasticity (δ) and standard deviations (σ) for Japan and other stock indexes. The test statistics are obtained from Fisher Z transformations. The stable period is defined as the 12-month pre-earthquake period (March 11, 2010 to March 10, 2011). The short-term turmoil period is defined as the 1-month post-earthquake period (March 11, 2011 to April 10, 2011). The medium-term turmoil period is defined as the 2-month post-earthquake period (March 11, 2011 to May 10, 2011). The full period is the stable period plus the medium-term turmoil period. Co: contagion .While "Y" denotes that the test statistics is greater than the critical value and contagion occurred, "N" indicates that the test statistics was less or equal to the critical value and no contagion occurred. ρ*stp, ρ*mtp, denote adjusted correlation coefficients for the short and medium term periods respectively. δ: correlation coefficient adjuster.

Note 3: Correlation coefficients are adjusted for heteroscedasticity using Equation 2.

5. Discussion of Results

This study has investigated if the March 2011 Japanese earthquake, tsunami and nuclear disaster affected the stability of the correlation structure in international stock and foreign exchange markets.

On a first note, with respect to international equity markets there is strong evidence of contagion in Taiwan, Bahrain, Saudi Arabia and South Africa. The effect on Saudi Arabia is not unexpected because it is one of the four countries from which a large part of Japan's imports in raw material originate. For the other three, cross-market correlations strengthened only with China and Australia in the short-term, albeit insignificant to account for contagion. An explanation as to why Saudi Arabia was most strongly affected both in the immediate and medium terms may be determined from Japan's boost in fuel imports in substitution to energy provided by wrecked the Fukushima nuclear plants. Bahrain, being an oil-export driven economy like her sisterly neighbor Saudi Arabia, could not have suffered a different fate. As for Taiwan, Japan is its second largest trading partner and official estimates on the effect of the Japanese earthquake on the Taiwanese economy stand at a yearly decline in growth by 0.2% of Gross Domestic Product (GDP).

Secondly, international foreign exchange market results indicate no presence of contagion. Admittedly, one would have expected the widespread disruption to Japan's US$5.5 trillion economy to inevitably affect other countries in the Asia-Pacific region and beyond. Regional trade would have been immediately affected by the damage to Japanese ports. Our unexpected findings could be explained from the fact that major

Japanese manufacturers of automobiles, semiconductors, computers and other goods immediately took advantage of their international supply chains and production networks; therefore moving production elsewhere in Asia or to North America, where capacity utilization is still low. Also, since Japanese factories generally produce consumer goods rather than intermediate products, disruptions to outbound shipments should not have been expected to seriously affect production processes in other countries.

As to what concerns managing and mitigating spillovers and contagion, it is worth pointing-out that globalization comes with costs and benefits. Hence managing financial market contagion resulting from natural disasters requires that governments minimize the costs and maximize the benefits of financial market integration. Most countries in the sample have undoubtedly benefited from integration, however based on the above empirical evidence, measures need to be taken in an effort to manage the downside ramifications of integration in the event of a natural disaster.

The following are some recommendations policy makers need to put in place in order to minimize(mitigate) the adverse financial market effects of disasters. (1) The banking system of a country should not be directly exposed to foreign assets that natural disasters can easily stress and make worthless. This recommendation also holds for assets in institutions that natural disasters could render futile. This will mitigate the knock-on effects through monetary, financial and real channels. (2) Domestic financial markets (equity, money, foreign exchange and credit markets) may also suffer because of the 'substitution effect'. As credit lines and credit channels in the affected and contaminated countries run dry, some of the credit-demand earlier met by overseas financing could easily shift to the domestic sector and put pressure on domestic resources. The reversal of

capital flows arising from the de-leveraging process could put pressure on the foreign exchange market, leading to sharp fluctuations in overnight money market rates and depreciation of currency. It is therefore in the interest of central banks to adopt a monetary policy stance that is adequate to growth, inflation and financial stability concerns. (3)In situations where the natural disaster reflects an expected decline in inflation, it is also in the interest of the central bank to adjust its monetary stance and manage liquidity: both domestic and foreign exchange to ensure that credit continues to flow for productive activities at both aggregate and sector specific levels. (4) In order to enable economic agents plan their business activities with more assurance, the central bank could ensure an orderly adjustment of the pain of its policies by maintaining a comfortable liquidity position: seeing that the weighted average overnight money market rate is maintained within the repo-reverse repo corridor and ensure conditions conducive for flow of credit to productive sectors (particularly the stressed export industry sectors).

Before we conclude, it is important to highlight the implications of this paper to the future of natural disasters. Though the crisis is over, from a financial standpoint the following concerns will preoccupy policy makers in future natural disasters. (1) Is self-insurance a viable option for emerging economies? In order words, could the accumulation of foreign reserves buffer against financial market crises arising from natural disasters? Whether these reserves derive from current account surpluses(China for instance) or capital flows(India for example), relying on them to hedge contagion could still represent some form of liability. Hence the need to find a way of balancing the trade-off between vulnerability to financial contagion and vulnerability to trade contagion in the event of a disaster. Another important strand within this framework points to the

redundancy of self-insurance if international arrangements(regional and multilateral) could provide easy, quick and unconditional liquidity during such crises. (2)How do policy makers keep the financial sector in line with the real sector in event of a natural disaster? Forgotten in the euphoria of financial alchemy is the basic tenet that the financial sector has no standing of its own; it derives its strength and resilience from the real economic sector. Thinking the other way round has led many into believing that, significant value could be created by slicing and dicing securities. (3) How do we address regulatory arbitrage in times of crisis? If under the nose of regulators, grows an extensive and complex network of a 'shadow banking system' that encourages loose practices, hunt for quick yields and non-transparent and risky financial products, when systems unravel owing to natural disasters, many of these institutions will pose a systematic risk to the financial systems. Hence the regulatory architecture has to be fashioned to keep pace with innovation and the possibility of natural shocks. (4)Simulating natural disasters and learning how to manage global imbalances arising from them could also help countries prepare for potential financial and real sector consequences of natural crises.

6. Conclusion

In this paper, we have used unadjusted and adjusted correlation coefficients to test for contagion effects across 33 economies in the aftermath of the Japanese earthquake, ensuing tsunami and worst nuclear crisis in recent history. Results indicate no international foreign exchange markets experienced significantly stronger correlations with the Japanese Yen two months after. However, for international stock markets, Taiwan, Bahrain, Saudi Arabia and South Africa experience contagion; consistent with the widely held notion that contagion is mostly a concern for emerging countries.

In line with Lee et al. (2007), the effects of natural disasters on financial markets are important in investment decisions, as the benefits of portfolio diversification are severely limited during periods of high volatility and increased cross-market correlations. With financial globalization, investors can gain from diversification if returns from financial markets are stable and not correlated. However with volatility spillovers, increase in cross-market correlations exist as a real effect and are not taken into account for asset allocation and portfolio composition.

Our results have two paramount implications. Firstly, we have confirmed the existing consensus that in the face of natural crises that could take an international scale, only emerging markets are contagiously affected for the most part. Secondly, we have also shown that international financial market transmissions not only occur during financial crises; natural disaster effects should not be undermined.

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