



## FINANCIAL ECONOMICS | RESEARCH ARTICLE

# Effect of catastrophic disaster in financial market contagion

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**Abstract:** The study examined the contagion effect of financial market volatility from Australian capital market to Indian, New Zealand, Hong Kong, Chinese, Taiwan, and Japanese capital markets due to Australian catastrophe. In the first stage, we employed two-variable vector autoregression (VAR) model for calculating the residuals of the daily index return. In the second stage, we used adjusted correlation coefficient for detecting the significant increase in correlation coefficient of the VAR residuals after the catastrophes. Finally, Fishers  $r$  to  $z$  transformation was used for identifying contagion. After Victoria bushfire, a significant increase in the adjusted correlation coefficient of Australia with India and Hong Kong and their respective  $z > +1.96$  validates contagion. The adjusted correlation coefficient of Australia with China and Japan increased after the Victoria bushfire but the  $z < +1.96$  with ( $p > 0.05$ ) does not confirm contagion, but rather exposed the persistence of high economic linkage. Apart from this, a significant decrease in the correlation coefficients with New Zealand is evident with corresponding  $z < -1.96$  and ( $p < 0.05$ ) advocates low economic linkage among them. After New South Wales (NSW) bushfire, contagion



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### ABOUT THE AUTHOR

Md. Noman Siddiquee is an adjunct assistant professor of Finance at the Department of Business Administration of City University, Khagan, Bangladesh. He was a permanent assistant professor of Finance at the Department of Business Administration of International Islamic University Chittagong, Bangladesh. Basically, Siddiquee is a financial market researcher and continuously doing research about financial market efficiency, factors affecting market volatility, and contagion effect. Already he has published two research articles about stock market efficiency and market volatility and one research article about portfolio performance analysis in investing Islamic banks' security of Bangladesh. Mostly, he is doing parametric research work using various econometric models. Now, Siddiquee is broadening his research interest about various catastrophic disasters and environmental effect in the global financial markets under the supervision of Mohammad Mafizur Rahman, senior lecturer of Economics at the Department of Economics and Banking of School of Commerce, University of Southern Queensland (USQ), who is also the co-author of this research article and the proposed PhD supervisor of Siddiquee at USQ.

### PUBLIC INTEREST STATEMENT

In recent times, Victoria and New South Wales (NSW) bushfires affected the Australian economy in many ways; declined the agricultural productivity and economic growth; destroyed many small and medium businesses; dropped the profitability in tourism industry in those areas; and increased the stock market volatility of Australia after approximately a month of those catastrophes. Besides, many qualified human resources died in those disasters whose exact economic values are uncountable yet. This particular paper investigates the extent of the said catastrophes to the Australian capital market and also more importantly examined the contagion (volatility transmission effect) of the said bushfires in the capital markets of India, New Zealand, Hong Kong, China, Taiwan, and Japan using ex-ante and ex-post market index value. The study found, after Victoria bushfire, contagion occurred from Australia to India and Hong Kong and after NSW bushfire, it occurred in Hong Kong only.

persists only between Australia and Hong Kong and the economic linkage of Australia and Taiwan has notably increased. The negative z score with ( $p > 0.05$ ) confirms absence of contagion effect in New Zealand, India, and Japan after shocks. The findings of the study recommend the Hong Kong and Indian investors to carefully examine the catastrophe-sensitive industry before taking major investment decisions.

**Subjects:** Environment & Agriculture; Environmental Studies & Management; Development Studies, Environment, Social Work, Urban Studies; Economics, Finance, Business & Industry

**Keywords:** financial market volatility; contagion; environmental catastrophe

**JEL classifications:** C01; E44; G15

## 1. Introduction

Australia has a long history of natural disaster, and in recent times, due to climate change and increase in global temperature, catastrophic disasters are very frequent in the country. During the last decade, Australia has witnessed a huge number of natural disasters like Storm, Tornado, Cyclone, Earthquake, Bushfire, and Floods. The Victoria Bushfire (2009) also named as Black Saturday bushfire, New South Wales (NSW) bushfires (2013) and recent Western Australian bushfire (2014) draw the attention of today's economists and policy-makers as they have long-term adverse impact on the economy. The average annual cost of natural disaster in Australia was \$1.2 billion per year from 2000 to 2012 and the highest cost (\$5.23 billion) was incurred in 2011 (Deloitte, 2013). The costs of Australian natural disaster are continuously increasing due to the advanced reporting system and increasing number of population at vulnerable areas in recent times. In 2015, total economic cost of natural disaster had crossed AU\$9 billion in Australia which is equivalent to 0.60% of its GDP and expected to be doubled in 2030. Besides, it is argued that economic costs of disasters are approximately underestimated by 50% in Australia (Deloitte, 2016).

Impact of natural disaster can be classified into two categories, economic and financial. Economic loss includes tangible impact which is directly countable like value of infrastructure, vehicles and loss of production. Intangible impact includes cost of death, injury and stress associated with the death and sickness. Financial loss of natural disaster only accounts direct financial loss of individual and enterprise where market price of assets is the mode of cost-benefit analysis (Worthington, 2008). Environmental shocks have sector-sensitive influence to the stock market return of Australia (Worthington & Valadkhani, 2005) where bushfires, cyclone and earthquakes have major adverse impact to the market return compared to storm and flood (Worthington & Valadkhani, 2004). Australia is the 13th largest economy in the world according to nominal GDP in 2015 with the 7th highest per capita GDP in 2015 (International Monetary Fund World Economic Outlook, 2015). Any economic movements of Australian capital market simultaneously impact its partner countries' economies too.

Australian capital markets are diversely connected with many capital markets due to globalization. Unanticipated transmission of shocks among the stock markets of other countries may take place due to contagion. Contagion is a cross-border spillover effect of financial shocks. According to Forbes and Rigobon (2001), when shocks of one market rapidly transmit to other markets and correlation increase significantly, contagion persists there. However, they also note that if the correlation between two countries is high before the transmission of shocks and remains the same or slightly increases but does not change significantly after the transmission of shocks, this is not necessarily a contagion; rather, high economic linkage prevails between the countries. The World Bank (2009) classifies contagion into three categories. Firstly, cross-country transmission of shocks can occur in real, economic or any other form which may relate to the crisis period but not necessarily always. Secondly, contagion is defined as the existence of significant co-movement of correlation after controlling the impact of any cross-border common shocks. Finally, cross-country correlation increases in crisis period compared to relatively stable period which may not comply with any underlying economic theory.

After any disaster, researchers mainly concentrate on causes and direct physical losses of the disaster. Most of those research works are in the fields of social and environmental sciences. Researches regarding the long-term impact on the economy, especially the impact on capital markets, are fairly limited. Some studies tried to explore the relationship between natural disaster and economic growth (see, for example, Benson & Clay, 2004; Cavallo & Noy, 2010; Kim, 2011; Wang & Kutan, 2013). Some studies tried to examine the linkage between natural disaster and capital market movement (see, Luo, 2012; Worthington, 2008; Worthington & Valadkhani, 2004) and some studies tried to examine the contagion effect in other market due to economic and financial shocks (see, Chiang, Jeon, & Li, 2007; Forbes & Rigobon, 2002; Khan & Park, 2009; Palamalai, Kalaivani, & Devakumar, 2013), but there is no study which examines the impact of natural disaster to the global markets. All those studies concentrate on different natural disasters of the world irrespective of country-specific consideration. Only Worthington (2008) studied the impact of natural disaster on the Australian capital market return. However, this study is not sufficient enough to explore the total impact of natural disaster in the Australian capital market except viewing a path of new research about the disaster impact across regions, sectors, industries, and companies. Our study is an extension of Worthington and Valadkhani's idea adding contagion effect of catastrophic shocks in other capital markets and this is the first work of contagion of catastrophic shocks, to the best of our knowledge.

The aim of this study is to investigate the impact of Victoria and NSW bushfires in the market volatility of the Australian equity market and the persistence of volatility transmission from Australian equity market to the sample countries' capital market.

## 2. Catastrophic disaster and international markets

Worthington and Valadkhani (2004) find that bushfires have significant positive impact on the capital market return of Australia while cyclones have considerable negative impact on the market return. Besides, earthquake has mixed impact overall. The impact of bushfire is positive to the equity market return during the event day or exactly after four days of the disaster. On the other hand, cyclones have significant negative impact on the second and fifth days of the disaster, when return falls 25% more on the fifth day compared to the second day. The immediate impact of earthquake is negative on equity market return but it increases positively (60%) after five days. The findings of Ferreira and Karali (2015) suggest that catastrophic disaster does not have any significant impact on market volatility except Japan because some selected macroeconomic indicators worked as a mediator for controlling the effect of the disaster. This finding is somewhat contradictory with Luo (2012) who studied the impact of earthquake to the six major stock markets of Japan and surprisingly found the overall impact of earthquake is small and insignificant in all markets. However, they also recognized some specific shocks have both positive and negative effects depending on the shock-sensitive industries which partially acknowledge Ferreira and Karali's (2015) findings too. Wang and Kutan (2013) also agreed with Luo (2012) and conclude that natural disaster does not affect the composite stock market in Japan and USA but it significantly affects their insurance sector. They also exposed a positive wealth effect in Japan and a negative wealth effect in the USA.

Investors of New York Stock Exchange (NYSE) and American Stock Exchange AMEX (organized exchange) show insignificant response to the catastrophic disaster news compared to the investors of NASDAQ (over the counter market) who are quiet sensitive about disasters information (Thompson, Zaman, & Kirmani, 1994). A noteworthy negative abnormal return just before and immediate after the disaster was also found. Since all those markets are semi-strong form efficient, it is required to have information effect on the share price, but surprisingly the organized exchange like NYSE and AMEX's response to the catastrophic disasters is not complying with the market efficiency rule. These findings are approximately similar to the findings of Taimur and Khan (2015) who exhibit catastrophe events of 1, 5, and 10 days long do not affect the mean return of Karachi stock exchange (KSE); however, 15-day long events affect the mean return of KSE which also entails the absence of semi-strong form market efficiency at KSE.

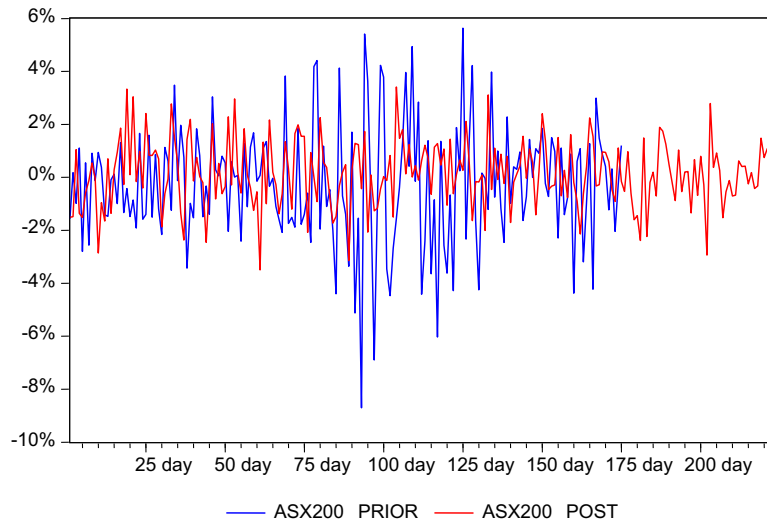
### 3. Event, data, and estimation methods

Australia is the shocks generating country and ASX300 (for the NSW bushfire) and ASX200 (for Victoria bushfire) are the base market indexes in our study. ASX300 is the newest index and gives wide exposure of Australian equity markets (approximately 73% of market capitalization, as of April, 2016). This index was introduced in 2013, so we choose it for examining the NSW bushfire impact. We set 7 February 2009 for the Victoria bushfire and 17 October 2013 for the NSW bushfire as disaster events because these are the most recent environmental catastrophes in Australia. Next, we examine the transmission of these shocks to the capital markets of New Zealand (NZX), India (BSE), China (SSE), Hong Kong (HENGSENG), Taiwan (TSEC), and Japan (NIKKE) as these countries' capital markets are highly connected with the Australian capital markets. We have collected daily stock index value of the respective country. All the data are collected from the respective stock exchange websites.

For estimation purpose, we calculate the logarithmic market return of each index using the formula  $r_t = \log(p_t/p_{t-1})$  where  $p_t$  is today's prices and  $(p_{t-1})$  is yesterday's price. The samples are then divided into prior and post-shocks return for the both (Victoria and NSW) bushfires. Prior shocks data consist of the daily market return from 1 June 2008 to 6 February 2009 for the Victoria bushfire and from 1 January 2013 to 15 October 2013 for the NSW bushfire. The post-shocks data include the daily market return from 15 February 2009 to 30 August 2009 for the Victoria bushfire and from 21

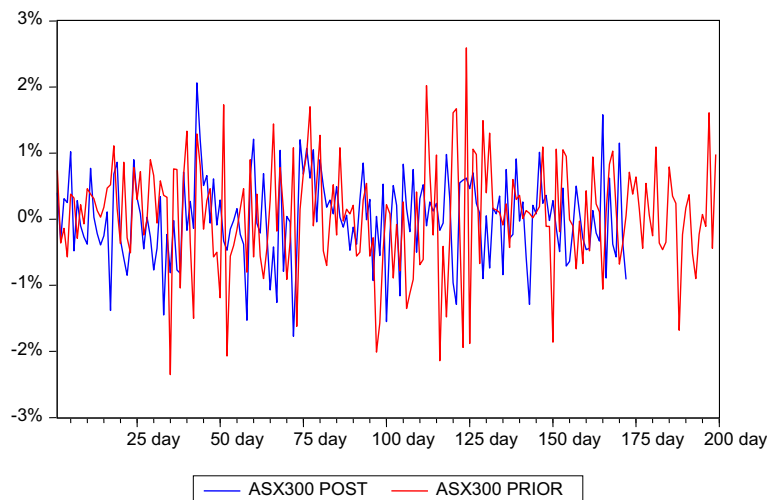
**Figure 1. Daily log return of prior and post-Victoria bushfire.**

Note: Prior shocks sample consists of 176-day return and post-shocks sample consists of 224-day return for Victoria bushfire.



**Figure 2. Daily log return of prior and post-NSW bushfire.**

Note: Prior shocks sample consists of 200-day return and post-shocks sample consists of 173-day return for NSW bushfire.



October 2013 to 30 June 2014 for the NSW bushfire. We avoid disaster period for the excess fluctuation of market return during that time due to semi-strong form market efficiency.

In Figure 1, prior Victoria bushfire, the daily log return fluctuates ranging from  $-8.71$  to  $+5.63\%$ , whereas after shocks, it fluctuates only in between  $\pm 3.5\%$ . In Figure 2, the daily log return of the ASX300 varies in between  $-2.40$  and  $+2.60\%$  prior shocks and it swings ranging from  $-1.8$  to  $+2.1\%$  after shocks. Both these findings are clearly exhibiting less volatile distributional properties of the sample return after both catastrophes.

In Table 1, the variance of log return is exposed as a proxy of market volatility. After Victoria bushfire, the volatility in all markets declined, whereas after NSW bushfire, volatility remains the same in NZX, and declined in rest other countries. These findings also indicate low volatile episode of the daily market return after both catastrophes.

Tables 1–4 of Appendix 1 illustrate the descriptive statistics of the daily return of all market indexes. Overall, the distributional properties of the base index (ASX200 and ASX300) returns are not normally distributed before bushfire, but after shocks, they are approximately normal. Before the bushfire, both series are negatively skewed ( $-0.175$  in ASX200 and  $-0.266$  in ASX300) indicating higher probability of return decrease and a potential volatility clustering in the daily market return. But surprisingly after both catastrophes, the skewness of both series is relatively less negative ( $-0.028$  (ASX200) and  $-0.071$  (ASX300)) indicating less volatile return distribution. After the Victoria bushfire, the daily mean return increased to  $0.143$  from  $-0.280\%$  indicating the upward trend of

**Table 1. Variance of log return**

Index	Prior Victoria bushfire (%)	Post-Victoria bushfire (%)	Prior NSW bushfire (%)	Post-NSW bushfire (%)
ASX200 (Prior shocks)	0.052	0.016	0.007	0.004
NZX	0.020	0.007	0.003	0.003
BSE	0.094	0.042	0.013	0.007
HENGSENG	0.115	0.040	0.009	0.008
SSE	0.074	0.035	0.014	0.008
TSEC	0.053	0.022	0.006	0.003
NIKKE	0.104	0.026	0.032	0.017

**Table 2. The coefficient of two-variable VAR model (Victoria bushfire)**

Country	Prior Victoria bushfire			Post-Victoria bushfire		
	$\phi_{1,1}$ (lag 4)	$\phi_{1,2}$ (lag 4)	$\epsilon_i$	$\phi_{1,1}$ (lag 4)	$\phi_{1,2}$ (lag 4)	$\epsilon_i$
ASX200	0.0042	0.1279	-0.0026	-0.0373	0.1077	0.0016
NZ50	-0.0103	0.0099	-0.0014	0.0477	0.0016	0.0010
ASX200	-0.1435	-0.1612	-0.0040	-0.0207	0.03355	0.0015
BSE	0.1159	0.0639	-0.0022	-0.0205	0.0690	0.0029
ASX200	0.0485	0.0777	-0.0024	-0.0633	0.1739	0.0013
HENGSENG	-0.1013	-0.0933	-0.0042	0.1238	-0.0714	0.0024
ASX200	0.0300	-0.1829	-0.0033	-0.0055	0.1152	0.0017
SSE	0.0164	0.0881	-0.0022	-0.0331	-0.0456	0.0014
ASX200	0.0589	-0.0898	-0.0030	-0.0024	-0.0451	0.0017
TSEC	-0.1351	-0.0916	-0.0048	-0.0539	-0.0450	0.0030
ASX200	0.0603	0.1495	-0.0021	-0.0323	0.1024	0.0015
NIKKE	-0.0043	-0.0310	-0.0036	0.1005	0.0893	0.0013

**Table 3. The coefficient of two-variable VAR model (NSW bushfire)**

Country	Prior NSW bushfire			Post-NSW bushfire		
	$\phi_{1,1}$ (lag 4)	$\phi_{1,2}$ (lag 4)	$\epsilon_i$	$\phi_{1,1}$ (lag 4)	$\phi_{1,2}$ (lag 4)	$\epsilon_i$
ASX300	-0.0565	0.0037	0.0006	-0.0086	0.0941	-0.0000
NZX	0.0527	-0.0820	0.0007	-0.0323	-0.0197	0.0003
ASX300	-0.0627	0.0267	0.0006	-0.0843	-0.0148	0.0013
BSE	-0.0660	-0.1123	0.0003	-0.0174	-0.0024	0.0000
ASX300	-0.0373	0.1600	0.0006	-0.0036	0.0052	0.0000
HENGSENG	0.1547	-0.0327	-0.0000	0.0307	0.0347	0.0001
ASX300	-0.0344	-0.0809	0.0006	-0.0048	0.0451	0.0000
SSE	0.1820	-0.0547	-0.0002	0.0222	0.0792	-0.0002
ASX300	-0.0582	0.1322	0.0006	-0.0141	0.1004	-0.0000
TSEC	0.1191	-0.0082	0.0003	0.1500	-0.0756	0.0007
ASX300	-0.0673	0.0454	0.0006	-0.0026	-0.0011	0.0000
NIKKE	0.2736	-0.0925	0.0015	0.0611	-0.1006	0.0005

**Table 4. Unadjusted (conditional) correlation coefficient of ASX200 residuals with other markets (Victoria bushfire)**

Country	$\rho_{\text{post shock}}^u$ (conditional) Victoria bushfire (%)	$\rho_{\text{prior shock}}^u$ (conditional) Victoria bushfire (%)	(z)	p-value (two tailed)	Contagion
New Zealand (NZX)	24.31	40.98	-1.84	0.07	No
India (BSE)	9.33	-13.59	2.26	0.02	Yes
HENGSENG	14.75	-1.41	1.6	0.11	No
SSE	8.66	-3.54	1.2	0.23	No
TSEC	13.34	11.55	0.18	0.86	No
NIKKE	9.18	-5.27	1.42	0.16	No

ASX200 and after the NSW bushfire, it decreased to 0.005 from 0.056% directing downward trend of ASX300 return. skewness declined to around zero in HENGSENG (0.185) and TSEC (0.069) after the Victoria bushfire also verifies low volatile distributional properties of the sample return. After Victoria bushfire, skewness of BSE (1.960) and NIKKE (0.144) turns to positive indicating more positive daily return, whereas the skewness of SSE (-0.662) and NZX (-0.201) turns to negative confirming more negative return in those series. After the NSW bushfire, skewness of HENGSENG (-0.192) and NIIKKE (-0.297) increased and close to zero confirm less negative return fluctuations then prior shocks. On the other hands, the increased negative skewness of NZX (-0.341) and TSEC (-0.917) confirms more negative daily return fluctuation after the NSW bushfire. Skewness of BSE (0.440) and SSE (0.122) is positive after the NSW bushfire directing positive return fluctuations of the said indexes.

The kurtosis of both index returns (ASX200 and ASX300) is higher before both catastrophes representing leptokurtic distribution and after shocks, it is just around 3 (3.116 and 3.295) exhibiting approximately normal distribution of both samples. In other markets, after the Victoria bushfire, kurtosis declined to near 3 in HENGSENG (3.320), NIKKE (3.567), and NZX (3.125) suggesting an approximately normal distribution and increased in BSE (17.497), SSE (4.518), and TSEC (5.117) confirming no normal distribution. After the NSW bushfire, kurtosis declined in HENGSENG (3.669), NIKKE (3.325), and SSE (3.820) advocating approximately normal distribution, whereas it increased in NZX (6.075) and TSEC (4.789) recommending that distribution is not normal. The p-values of Jarque-Bera

test statistics expose the similar results of skewness and kurtosis about the normality distribution of the sample return. Prior to the both catastrophes, the Jarque–Bera test statistics ( $p < 0.05$ ) reject the normality assumption of both samples’ (ASX200 and 300) return; but after shocks, ( $p > 0.05$ ) it is confirmed that the return of both indexes is normally distributed. However, in other indexes, after the Victoria shock, the Jarque–Bera test statistics ( $p > 0.05$ ) of in the HENGSENG, NIKKE, and NZX indexes and after the NSW shock, it is confirmed that returns are normality distributed in HENGSENG, NIKKE, and SSE indexes with ( $p > 0.05$ ).

To measure contagion, we use unconditional correlation coefficient developed by Forbes and Rigobon (2002). Using the unrestricted two-variable vector autoregressive (VAR) model, we calculate each index return with ASX200 and ASX300, respectively. The VAR model is widely accepted in checking the dynamic behavior of financial time series data. We could use multivariate VAR model for capturing the overall dependencies of each market with others, but to measure the distinctive extent of correlation, we use the following two-variable VAR model.

$$y_{1,t} = c_1 + \theta_{1,1}y_{1,t-k} + \theta_{1,2}y_{2,t-k} + \varepsilon_{1,t} \quad (1)$$

$$y_{2,t} = c_2 + \theta_{2,1}y_{1,t-k} + \theta_{2,2}y_{2,t-k} + \varepsilon_{2,t} \quad (2)$$

where  $y_1$  represents ASX return in each pair and  $y_2$  the other market return. Both  $y_1$  and  $y_2$  are endogenous variables and  $\varepsilon_1$  and  $\varepsilon_2$  are the residuals/white noise disturbance terms of the equations and also the key components of our analysis. We select four lags ( $k = 4$ ) for avoiding autocorrelation in the data-set.

Our intention is to measure the impact of idiosyncratic shocks of one market to other market. So we calculate the daily white noise disturbance term of each market in both periods. According to OLS estimator,  $\sum \varepsilon_i = 0$ , implies each value of  $\varepsilon_i$  represents the unique reflection of the shock. Now let the residuals ( $\varepsilon_1$ ) of the shocks generating data-set of ASX be  $x$  and the other ( $\varepsilon_2$ ) be  $y$ . Next, we divide the sample ( $x$ ) into two groups, prior shocks sample denoted as  $x_{\text{prior}}$  and post-shocks sample denoted as  $x_{\text{post}}$  and likewise for other markets,  $y_{\text{prior}}$  and  $y_{\text{post}}$ . According to Forbes and Rigobon (2001), after shocks, it is expected that market volatility will increase and if so, then,

$$\sigma_{xx}^{\text{post}} > \sigma_{xx}^{\text{prior}} \quad (3)$$

$$\text{and, } \sigma_{xy}^{\text{post}} > \sigma_{xy}^{\text{prior}} \quad (4)$$

$$\text{therefore, } \rho_{xy}^{\text{post}} > \rho_{xy}^{\text{prior}} \quad (5)$$

This signifies any increase in the post-shocks correlation does not constitute contagion always because it is expected that after shocks, variance of  $x$  will increase due to potential increase in market volatility; consequently, the covariance of  $x$  and  $y$  will also increase. This subsequently increases the post-shock (unadjusted) correlation coefficient ( $\rho_{xy}^{\text{post}}$ ).

The Equation (6) below describes the unadjusted correlation coefficient.

$$\rho_t^u = \rho_t \sqrt{\frac{1 + \delta_t}{1 + \delta_t \rho_t^2}} \quad (6)$$

where  $\rho_t^u$  is the unadjusted (conditional) correlation coefficient and  $\rho_t$  is the correlation of the VAR residuals. After shocks, any increase in correlation coefficients up to ( $\delta_x$ ) is not contagion, rather a

**Table 5. Adjusted (unconditional) correlation coefficient of ASX200 residuals with other markets (Victoria bushfire)**

Country	$\rho_{\text{post shock}}^a$ (unconditional) Victoria bushfire (%)	$\rho_{\text{prior shock}}^a$ (unconditional) Victoria bushfire (%)	(z)	p-value (two tailed)	Contagion
New Zealand (NZX)	31.99	51.77	-2.38	0.02	No
India (BSE)	12.52	-18.17	3.04	0.00	Yes
HENGSENG	19.69	-1.89	2.15	0.03	Yes
SSE	11.63	-4.76	1.62	0.11	No
TSEC	17.84	15.47	0.24	0.81	No
NIKKE	12.33	-7.10	1.92	0.06	No

conditional bias (conditional to the variance of  $x$ ). In that case, correlations are not adjusted with  $\delta_x$  (Forbes & Rigobon, 2002). The relative extent of biases can be calculated as,

$$\delta_x \equiv \frac{\sigma_{x,x}^{\text{post}}}{\sigma_{x,x}^{\text{prior}}} - 1 \tag{7}$$

where  $\delta_x$  is the heteroskedasticity bias persistent in a time series data due to earlier shock. They also suggested for contagion, a significant increase in the unconditional (adjusted by  $\delta_t$ ) correlation of the two time series data is required after any shocks. The unconditional (adjusted) correlation coefficient is,

$$\rho_t^a = \frac{\rho_t^u}{\sqrt{1 + \delta_t[1 - (\rho_t^u)^2]}} \tag{8}$$

Finally, Fishers  $r$  to  $z$  transformation is used for examining the significance of difference between two independent samples' correlation. If  $z > 1.96$  for a two-tailed test and  $p \leq 0.05$ , contagion exists; otherwise, this is economic linkage. If the post-shocks correlation coefficient between  $x$  and  $y$  is more than prior shocks,  $z$  should be positive, and contagion will take place at  $z \geq +1.96$ . In that case, volatility will transmit from Australia to other country. And if the post-shocks correlation coefficient between two residuals is less than prior shocks,  $z$  should be negative which suggests economic linkage declined and if  $z \leq -1.96$ , economic linkage declined extensively. If the post-shocks correlation of the VAR residuals is positive and increases, but not significantly ( $z$  lies in between 0 and  $< +1.96$ ), a high economic linkage is persistent. And if after shocks correlation coefficient is negative between two residuals and decreases, but not significantly ( $z$  lies between 0 and  $> -1.96$ ), a low economic linkage is persistent.

#### 4. Findings and analysis

Tables 2 and 3 exhibit the coefficient of two-variable vector autoregression (VAR) model. We calculate two-variable VAR models where ASX200 and ASX300 are the dependent variables ( $y_1$ ) with respect to other country ( $y_2$ ). In Table 2, after Victoria bushfire, the coefficient of ASX200 lag return has full negative impact on the current market return of ASX200 but prior shocks, it has a positive impact on the current market return of ASX200 except with BSE (-0.1435). This is a good signal of persisting low return dynamics in the ASX200 after shocks. Besides, prior Victoria bushfire, ASX200 lag return has a negative impact on all other countries' return except BSE (0.1158) and SSE (0.0164), while after shocks, it has a negative impact on BSE (-0.0205), SSE (-0.0330), and TSECs (-0.0539) return only. Apart from this, BSE (-0.1612), SSE (-0.1829), and TSEC (-0.08978) have negative impacts on the ASX200 return before the Victoria bushfire, whereas after shocks, only TSEC has a negative impact (-0.04508) on ASX200 return.



**Table 6. Unadjusted (conditional) correlation coefficient of ASX300 residuals with other markets (NSW bushfire)**

Country	$\rho_{\text{post shock}}^u$ (conditional) NSW bushfire (%)	$\rho_{\text{prior shock}}^u$ (conditional) NSW bushfire (%)	(z)	p-value (two tailed)	Contagion
New Zealand (NZX)	6.62	10.90	-0.41	0.68	No
India (BSE)	1.92	15.46	-1.3	0.19	No
HENGSENG	11.48	-8.56	1.92	0.05	Yes
SSE	3.84	16.71	-1.24	0.22	No
TSEC	9.50	1.27	0.79	0.43	No
NIKKE	-0.75	11.46	-1.17	0.24	No

**Table 7. Adjusted (unconditional) correlation coefficient of ASX300 residuals with other markets (NSW bushfire)**

Country	$\rho_{\text{post shock}}^a$ (unconditional) NSW bushfire (%)	$\rho_{\text{prior shock}}^a$ (unconditional) NSW bushfire (%)	(z)	p-value (two tailed)	Contagion
New Zealand (NZX)	7.46	12.27	-0.46	0.65	No
India (BSE)	2.16	17.37	-1.47	0.14	No
HENGSENG	12.91	-9.64	2.16	0.03	Yes
SSE	4.32	18.76	-1.4	0.16	No
TSEC	10.69	1.43	0.89	0.37	No
NIKKE	-0.85	12.89	-1.32	0.19	No

Error term is positive in all equations after the Victoria bushfire and is fully negative before Victoria bushfire. This implies actual daily returns of all markets are comparatively low before the Victoria bushfire and high after shocks. Since, after shocks  $\varepsilon_2$  increased in all countries, it indicates a potential positive z score. However, if the post-shocks correlation of ASX200 with any other country is less than prior shocks, the z score will be negative.

In Table 3, the coefficient of ASX300 lag return has a negative impact on the current market return of ASX300 both prior and post-NSW bushfire. Apart from this, prior to the NSW bushfire, ASX300 lag return has a positive impact on all other countries' return except BSE (-0.066); and after shocks, it has a negative impact on NZX (-0.0323) and BSE (-0.0174) only. Besides, NZX, BSE, TSEC, and NIKKE's lag return has negative impact on their own current market returns after the NSW bushfire. This implies after shocks return of those indexes will decline.

The error term of all markets return is positive after the NSW bushfire except SSE (-0.0002) directing the higher actual return than estimated. In addition to this, error term only increased in HENGSENG (0.0001) and TSEC (0.0007) implying more actual return in these two markets. In other indexes (NZX, BSE, and NIKKE), error terms are less after shocks suggesting low actual daily return after the NSW bushfire.

Tables 4-7 exhibit the results of the study. In Table 4, the unadjusted correlation coefficient of the residuals of ASX200 with NZX declined to 24.31% and their  $z = -1.84$  with ( $p > .05$ ) confirms no contagion, rather a low economic linkage between Australia and New Zealand. And after heteroscedasticity adjustment,  $z = -2.38$  with ( $p < .05$ ) exposed economic linkage declined significantly after the Victoria bushfire. Besides, negative skewness, kurtosis value around 3 (3.125), and the variance of return declined from 0.020% to 0.007% in Table 1 also verify low volatile return distribution of New Zealand capital market after the Victoria bushfire.

Both unadjusted (9.33%) and adjusted (12.52%) correlation coefficients of the residuals of ASX200 and BSE increased significantly after shocks with  $z = 2.26$  and  $3.04$ , respectively, and ( $p < 0.05$ ) validate contagion in both cases. This entails, after shocks, higher percentage of volatility has transmitted from the Australian capital market to the Indian capital market. The unadjusted correlation coefficient of ASX200 and HENGSENG increased after shocks but the  $z = 1.6$  with ( $p > 0.05$ ) suggests higher economic linkage between Australia and Hong Kong. However, after heteroscedasticity adjustment,  $z = 2.15$  with ( $p < 0.05$ ) confirms contagion. The adjusted correlation coefficient of NIKKE is positive after shocks (12.33%) and the  $z = 1.92$  with ( $p = 0.06$ ) suggests high economic linkage and also affirms that if there is further increase in correlations, contagion will take place.

The findings of BSE, HENGSENG, and NIKKE are contradictory with their return volatility displayed in Table 1, where prior to the Victoria bushfire, the volatility of ASX200, BSE, HENGSENG, and NIKKEs is 0.052, 0.094, 0.115, and 0.104%, respectively, whereas after shocks, these are 0.016, 0.042, 0.040, and 0.026%. In all markets, volatility declined according to the Table 1, but increased according to the adjusted correlation coefficient. These contradictory findings produce a confusion in deciding whether volatility is transmitted from Australia to those countries or not? The logical explanation of this conflict is that though volatility level declined after shocks in the above markets which is also verified from their kurtosis results, the percentage of volatility transmission increased after shocks rather than few big fluctuation transmissions. The adjusted correlation coefficient of SSE increased after the Victoria bushfire and their corresponding  $z = 1.62$  with ( $p > 0.05$ ) confirms high economic linkage between Australia and China and the findings of TSEC suggest a moderate increase in economic linkage between Australia and Taiwan.

In Tables 6 and 7, both unadjusted ( $\rho_t^u = 11.47\%$ ) and adjusted ( $\rho_t^a = 12.91\%$ ) correlation coefficient of ASX300 with HENGSENG increased significantly after the NSW bushfire. The  $z$  value of adjusted correlation coefficient is 2.16 and with corresponding ( $p < 0.05$ ) confirms contagion. This implies higher percentage of volatility has transmitted from the Australian capital market to the Hong Kong capital market after the NSW bushfire. But these results are also contradictory with Table 1 again, where the volatility of HENGSENG (0.008%) declined slightly after the NSW bushfire and the respective skewness ( $-0.192$ ) and kurtosis (3.669) also declined suggesting low volatile distributional properties of the Hong Kong return. The explanation of this conflict is the same as before: the rate of volatility transmission has increased from the Australian capital market to the Hong Kong capital market rather than a small number of gigantic fluctuation transmissions in HENGSENG return.

In other markets, ( $p > 0.05$ ) of adjusted correlation coefficient confirms no contagion, rather varying degrees of economic linkage after NSW bushfire. The after shocks-adjusted correlation coefficient of ASX300 with NZX (7.46%), BSE (2.16%), and SSE (4.32%) increased but not significantly and their corresponding  $z$  score is  $-0.46$ ,  $-1.47$ , and  $-1.4$  pointing out no contagion between Australia and these countries. Apart from this, the volatility level remains the same prior and post-shocks in these countries and the mean return of NZX and SSE declined after shocks again signaling the less volatile return distribution in those markets.

The after shocks correlation of ASX300 and NIKKE ( $-0.008\%$ ) and the  $z = -1.32$  with ( $p > 0.05$ ) confirms persistence of no contagion between the Australian and Japanese capital markets. Only TSEC's adjusted correlation coefficient increased significantly (10.69%) after the NSW bushfire indicating the probability of higher percentage of volatility transmission from Australia to Taiwan. But since the  $z < 1.96$  (0.89) and the corresponding ( $p > 0.05$ ), we cannot verify its contagion; rather, it might be a high economic linkage.

## 5. Conclusion

This study has quantified the long-term influence of bushfire on the Australian capital market as well as the contagion effect of the Australian catastrophe on other countries' capital market. For doing this, firstly, we have divided the data-set into two groups, prior shocks return and post-shocks return.

The variance of logarithmic return stands for the market volatility in our study. Interestingly, primary findings verify that all markets experienced low volatility after both catastrophes except New Zealand. However, the volatility levels remain the same in New Zealand after the NSW bushfire. This implies that the provided shocks of catastrophic disasters do not increase the market volatility of any countries. Furthermore, we examined the contagion effect of the said disasters on other countries' capital market. In that case, we mainly test the impulse response of idiosyncratic shocks attributed in the daily market return using the adjusted correlation coefficient of the VAR residuals. Our findings suggest that correlations exert a higher percentage of volatility transmission in the Indian and Hong Kong capital markets due to the Victoria bushfire. And after the NSW bushfire, a higher percentage of volatility has transmitted from Australia to Hong Kong only. These findings conclude that the capital markets of India and Hong Kong are quite sensitive to the Australian catastrophes. So the investors of these two countries need to keep keen eyes on the Australian disasters before taking any investment decision.

It was believed earlier that in the long run environmental catastrophes directly affect the country's GDP only, but the existing literature and this study suggest that catastrophes also directly affect the capital market of a country, and due to globalization, these influences can transmit quickly in other markets. It is impossible to stop the catastrophe and even it is very hard to control the effects of disasters on the economy. However, more precise loss estimation, accurate economic and financial influence measurement, and appropriate policy formulation for controlling the adverse effects of catastrophes can ensure the stable capital market.

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## Appendix 1

Table 1. Descriptive statistics of the daily log return series, prior Victoria bushfire

	ASX200	BSE	HENGSENG	NIKKE	NZX	SSE	TSEC
Mean	-0.280%	-0.318%	-0.363%	-0.339%	-0.139%	-0.264%	-0.395%
Median	-0.229%	-0.296%	-0.145%	-0.143%	-0.048%	-0.338%	-0.202%
Maximum	5.628%	7.901%	13.407%	13.235%	5.815%	9.034%	6.099%
Minimum	-8.704%	-11.604%	-13.582%	-12.111%	-4.938%	-8.044%	-5.933%
Std. dev.	2.288%	3.061%	3.397%	3.229%	1.427%	2.722%	2.298%
Skewness	-0.175	-0.071	0.379	-0.136	-0.109	0.264	0.142
Kurtosis	3.995	3.540	6.243	6.220	5.065	4.006	3.262
Jarque-Bera	8.110	2.274	80.865	76.147	31.429	9.424	1.092
Probability	0.017	0.321	0.000	0.000	0.000	0.009	0.579

Table 2. Descriptive statistics of the daily log return series, post-Victoria bushfire

	ASX200	BSE	HENGSENG	NIKKE	NZX	SSE	TSEC
Mean	0.143%	0.277%	0.213%	0.137%	0.084%	0.124%	0.255%
Median	0.096%	0.181%	0.105%	0.168%	0.119%	0.290%	0.298%
Maximum	3.409%	15.990%	7.153%	5.026%	2.374%	5.936%	6.525%
Minimum	-3.502%	-6.008%	-4.965%	-4.637%	-2.595%	-6.983%	-4.115%
Std. dev.	1.261%	2.059%	1.995%	1.607%	0.859%	1.880%	1.470%
Skewness	-0.028	1.960	0.185	0.144	-0.201	-0.662	0.069
Kurtosis	3.116	17.497	3.320	3.567	3.125	4.518	5.117
Jarque-Bera	0.154	2,095.456	2.222	3.756	1.642	37.712	41.806
Probability	0.926	0.000	0.329	0.153	0.440	0.000	0.000

Table 3. Descriptive statistics of the daily log return of ASX300, prior NSW bushfire

	ASX300	BSE	HENGSENG	NIKKE	NZX	SSE	TSEC
Mean	0.056%	0.020%	0.001%	0.148%	0.068%	-0.012%	0.035%
Median	0.098%	0.050%	0.000%	0.178%	0.081%	0.009%	0.010%
Maximum	2.592%	3.704%	2.517%	4.826%	1.707%	3.333%	2.237%
Minimum	-2.354%	-4.054%	-2.920%	-7.597%	-1.409%	-5.445%	-2.416%
Std. dev.	0.815%	1.129%	0.972%	1.784%	0.545%	1.163%	0.756%
Skewness	-0.266	-0.179	-0.259	-0.756	-0.081	-0.514	-0.106
Kurtosis	3.701	4.482	3.857	5.110	3.508	5.951	3.601
Jarque-Bera	6.412	19.284	8.318	55.889	2.354	80.940	3.363
Probability	0.041	0.000	0.016	0.000	0.308	0.000	0.186

Table 4. Descriptive statistics of the daily log return of ASX300, post-NSW bushfire

	ASX300	BSE	HENGSENG	NIKKE	NZX	SSE	TSEC
Mean	0.005%	0.112%	-0.006%	0.018%	0.027%	-0.051%	0.060%
Median	0.010%	0.060%	0.008%	0.015%	0.009%	-0.065%	0.131%
Maximum	2.061%	2.868%	2.690%	3.080%	1.995%	2.834%	1.203%
Minimum	-1.766%	-2.037%	-2.936%	-4.267%	-2.265%	-2.901%	-2.369%
Std. dev.	0.642%	0.837%	0.888%	1.318%	0.506%	0.904%	0.572%
Skewness	-0.071	0.440	-0.192	-0.297	-0.341	0.122	-0.917
Kurtosis	3.295	3.491	3.669	3.325	6.075	3.820	4.789
Jarque-Bera	0.766	7.275	4.256	3.276	71.120	5.248	47.058
Probability	0.682	0.026	0.119	0.194	0.000	0.073	0.000



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