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Did the S.A.R.S. epidemic weaken the integration of Asian stock markets? Evidence from smooth time-varying cointegration analysis

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ABSTRACT

The purpose of this study is to examine the effect of the Severe Acute Respiratory Syndrome (S.A.R.S.) epidemic on the long-run relationship between China and four Asian stock markets. To this end, we first employ the advanced smooth time-varying cointegration model to investigate the existence of a time-varying cointegration relation among these markets and then employ the difference-in-differences approach to analyse whether or not the S.A.R.S. epidemic impacted the long-run relation between China and these four markets during the period 1998–2008, covering 5 years before and after the S.A.R.S. outbreak. Our results support the existence of a time-varying cointegration relation in the aggregate stock price indices, and that the S.A.R.S. epidemic did weaken the long-run relationship between China and the four markets. Therefore, stockholders and policy makers should be concerned about the influence of catastrophic epidemic diseases on the financial integration of stock market in Asia.

1. Introduction

The recent human crises of Zika, Ebola, and M.E.R.S. (Middle East respiratory syndrome) epidemically spiralling out of control remind us that countless lives were also lost and trillions of dollars in economic damage were incurred during the Severe Acute Respiratory Syndrome (S.A.R.S.) outbreak of 2002–2003. Unfortunately, even with many published articles spanning over several years, little is known about how epidemic diseases affect stock market integration, leaving a gap in the literature to be filled in by future research. Risk management deals with the distribution of outcomes that deviate from their expected value (Rufino, 2011). Rather than focusing on the centre of the distribution, risk management directs its attention in describing the behaviour in the extremes (Jorion, 2007). According to Dowd (2007), the S.A.R.S. outbreak (i.e., unexpected natural catastrophes)

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and the recent financial crisis are examples of the Low Frequency High Severity event. Longin and Solnik (2001), using extreme value theory, find that the correlation increases in bear markets but not in bull markets and is unrelated to market volatility. Hartmann, Straetmans, and De Vries (2004) measured the expected number of stock and bond market crashes by following extreme value theory. Onay and Ünal (2012) explore the long-term financial integration and extreme dependence between two stock markets, and find that while episodic cointegration exists for the sample markets, the extremes of these markets still possess asymptotic independence, suggesting diversification opportunities. Therefore, this study, based on extreme value theory, explores the impact of unexpected high severity event (S.A.R.S.) on financial market integration.

Apart from previous research on stock market integration predominantly exploring financial crises or European Union-related issues (e.g., Rughoo & You, 2015; Ogrokhina, 2015; Bekiros, 2014; Christiansen, 2014; among others), this research initially clarifies the impacts of the S.A.R.S. outbreak on cross-country stock market integrations of the countries that were highly infected, less infected countries, and the disease's sourcing country. An analysis of the impacts of epidemic diseases is vital because severe epidemic diseases are a recurrent phenomenon with serious consequences for human life and the real economy. Therefore, this research presents for the first time a new linkage between human health and stock market integration.

The World Health Organisation (W.H.O.) database shows that the S.A.R.S. infection period was from 2002/11/1 to 2003/8/7. This specific empirical procedure, aiming to investigate the S.A.R.S. epidemic impacts on the long-run relationships in aggregate stock price indices within an integrated market, includes the following two steps. First, this study applies the smooth time-varying cointegration (S.T.V.C.) model to test for whether or not time-varying cointegration relationships among China and four Asian stock markets exist during the period 1998–2008. Second, we employ the difference-in-differences (D.I.D., hereafter) approach by separating our sample countries into a minorly infected country (Japan), highly infected countries (Hong Kong, Taiwan, and Singapore), and the sourcing country (China) to examine whether the S.A.R.S. epidemic weakened the time-varying long-run relation (measured by the time-varying coefficients obtained from the S.T.V.C. model) among these countries during our study period.

S.A.R.S. started as a mystery illness (i.e., without name, origin, or cure) and first appeared in Guangdong Province, China in November 2002. The disease then spread to 37 countries, infected more than 8,422 people, and claimed 916 lives (De Lisle, 2003; Lee & McKibbin, 2004a; Siu & Wong, 2004; Wang & Jolly, 2004). The cost of the 2003 S.A.R.S. outbreak was as high as that from the Asian financial crisis, estimated at $3 trillion in lost GDP and $2 trillion in fallen equity in the financial markets (De Lisle, 2003). S.A.R.S. had a far higher economic shock than expected given its health impact (Barreto, 2003; Blendon, Benson, DesRoches, Raleigh & Taylor-Clark, 2004). Additionally, examining global stock market integration is a central issue in finance given the implied consequences for asset allocation decisions and portfolio diversification (Graham, Kiviaho & Nikkinen, 2012). A strongly integrated international stock market implies little or no international diversification benefits (Graham et al., 2012). Internationally-segmented stock markets, on the other hand, enable portfolio managers to diversify and take advantage of the differences in the various markets (Graham et al., 2012). Market integration related studies have looked at specific events such as financial crises (Chevapatrakul & Tee, 2014; Răileanu-Szeles & Albu, 2015), the European

Union (or Euro monetary union) implementation (Christiansen, 2014; Ogrokhina, 2015), political crises (Frijns, Tourani-Rad & Indriawan, 2012), and air crashes (Ho, Qiu & Tang, 2013), but it remains an open question as to whether these unexpected crises will weaken or strengthen the long-run relationship in aggregate stock price indices within an integrated market. For example, Yu, Fung, and Tam (2010) show that the equity market integration process of A.S.E.A.N.+3 (Association of Southeast Asian Nations) countries picked up in 2007–2008, while Wang (2014) identifies that the global financial crisis has strengthened the linkages among stock markets in East Asia, signifying that time-varying long-run relationships exist among these countries. Hemche, Jawadi, Maliki, and Cheffou (2016) find a substantial increase in dynamic correlations following the recent subprime crisis for most markets under consideration with regard to the U.S. market. Narayan, Sriananthakumar, and Islam (2014) also present that relations between Asian and U.S. markets were strongest during the global financial crisis, while Frijns et al. (2012) show that political crises generally reduced the level of stock market integration in 19 emerging countries from the South and East Asia, Latin American, and Central and Eastern Europe regions. Rughoo and You (2015) note evidence of both global and regional integrations in the money market pre-2008, but once the crisis hit, the process of global integration came to an abrupt halt. During the recent crisis period, Christiansen (2014) pinpoints that government bond market integration was weaker.

To our knowledge, only one research in the literature has looked at S.A.R.S. and its related impact on stock markets. Nippani and Washer (2004) investigate the impact of S.A.R.S. on several countries' stock markets using Mann–Whitney non-parametric tests. On the basis of the theoretical framework derived from the efficient-market theory and rational expectations intertemporal asset-pricing theory (Chen, Roll & Ross, 1986; Merton, 1973), whenever a particular asset is influenced by systematic economic news, no extra reward can be earned by bearing diversifiable risk. This implies that a strong relation between S.A.R.S. and market integration is possible. On the other hand, a severe epidemic disease outbreak may increase the level of investors' risk aversion. This increased risk aversion may cause them to withdraw money from these disease-sourcing or infected markets. This could depress those markets and could also reduce their level of integration with other markets since investors could perceive more risk, leading to less foreign investment being set up in the infected markets than that in the non-infected markets. Thus, the result is still inconclusive.

Early research on financial market integration uses a range of different methodologies, such as cointegration and vector error correction models (e.g., Aggarwal & Kyaw, 2005; Bentes, 2015; Kleimeier & Sander, 2000), general regression methods (De Nicolò & Juvenal, 2014; Morelli, 2010), copula (Kumar & Okimoto, 2011), or Kalman filter (Kim, Moshirian & Wu, 2006), to name just a few. However, Graham et al. (2012) indicate that the degree of co-movement is not constant over time. It is indeed hard to assume that long-run relationships among stock market indices remain constant. Modelling asset market integration without considering the time-varying nature of financial linkages may result in misleading conclusions (Martins & Gabriel, 2014). Martins and Gabriel (2014) suggest that the degree of integration across equity markets is better viewed as time-varying. Following Zuo and Park (2011), this study is the first to apply a S.T.V.C. model, which is designed to deal with the nature of the time-varying long-run relationship in aggregate stock price indices among integrated regional markets.

There is a far-reaching theoretical perception that financial markets may be characterised by non-linear behaviour resulting from the co-existence of heterogeneous investors, the presence of transaction costs, as well as the existence of friction in the stock market (Chang & Liu, 2010; McMillan, 2003), such that the size of the deviation from the deterministic trend influences stock price dynamics. Specifically, when modelling the behaviour of real stock prices, the intuition behind this specification is that the real stock price is non-stationary and follows a random walk if it was close to its long-run equilibrium value in the past period. There are driving forces based on arbitrage that lead to mean-reversion if the real stock prices depart from their long-run equilibrium. Furthermore, arbitrage may not be profitable if the departure is small, and thus the degree of mean-reversion will be small as well, and vice versa. As China is the S.A.R.S.-originating country and the spread of S.A.R.S. was quick to several Asian countries, we therefore examine the effect of the S.A.R.S. epidemic on the long-run nonlinear relationship between China and four Asian stock markets.

Our empirical results suggest that the time-varying cointegration relations in the aggregate stock price indices between China and the four Asian sample countries (Hong Kong, Taiwan, Singapore, and Japan) did exist during our study period. After taking the possible economic impacts from the Asian financial crisis, dotcom bubble, and subprime mortgage crisis into account, we find that the S.A.R.S. epidemic weakened the long-run relationship between China and the four other stock markets. Since the number of deaths in Hong Kong, Taiwan, and Singapore were respectively 300, 180, and 33 during our study period (W.H.O. S.A.R.S. database), our results echo the findings from Ho et al. (2013) in that an epidemic disease outbreak and an air crash with a higher degree of fatalities may have a larger and more persistent negative impact on stock prices. The significance of this study is threefold. First, S.T.V.C. is better than the traditional cointegrating regression model for estimating the cointegration relationship between sample countries. The traditional cointegrating regression model is based on the assumption of a 'constant' long-run relationship. Thus, when there are structural changes in the long-run relationship, the traditional model cannot accommodate such changes and therefore rejects the existence of a cointegration relationship (Park & Zhao, 2010). However, such structural changes can be implemented in the S.T.V.C. model (Park & Zhao, 2010). Second, this study clarifies the impact of S.A.R.S. on cross-country stock market integrations for treated groups and control groups, as well as treated period (S.A.R.S. period) and control period (post-S.A.R.S.) by adopting the difference-in-differences approach (D.I.D.), which is relatively free from the endogeneity problem. Third, we find the existence of the time-varying cointegration relation in the aggregate stock price indices between China and the other four Asian countries during our sample period. However, the uniqueness of our finding is that the S.A.R.S. epidemic did weaken the long-run relationship between China and these four Asian stock markets.

2. Literature review

The effect of the S.A.R.S. epidemic on an economy is potentially important, particularly as its origin source was China, which has been a key centre of foreign investment in Asia, and in 2002 the disease began to have a domino effect throughout regional economies (Lee & McKibbin, 2004b). The spread of S.A.R.S. to several countries (notably Vietnam, Singapore, and Canada) brought worldwide attention to the issue that it was a deadly new disease and was spreading quickly (Siu & Wong, 2004). Globalisation increases the likelihood that an

infectious disease appearing in one country will spread rapidly to another, and outbreaks of more serious diseases could cause catastrophic impacts on the global economy (Smith, 2006). The impact of the S.A.R.S. epidemic on human society around the world is striking, not just because the disease spread quickly across countries through global travel, but also because any economic shock to one country quickly spread to others due to financial integration and globalisation (Lee & McKibbin, 2004a). Contrary to logic, Siu and Wong (2004) find no anecdotal evidence to indicate that the S.A.R.S. epidemic had negative effects on either domestic or global investment. Koo and Fu (2003) report that despite the serious emotional distress it caused, the S.A.R.S. epidemic appears to have had limited and temporary economic impacts in the region. Therefore, there is no consensus yet on the existence of a S.A.R.S. epidemic affecting economic activities, and thus it is important to go beyond the rough estimates that currently permeate the commentary of its economic consequences.

Most previous studies on the economic effects of epidemics focus on disease-associated medical costs or economic effects as a result of disease-related morbidity and mortality. For example, Chou, Kuo, and Peng (2003) and Siu and Wong (2004) provide findings of the economic effects of the S.A.R.S. epidemic on individual countries, such as China, Hong Kong, and Taiwan. The unfortunate situation created by the S.A.R.S. epidemic gives us a unique opportunity to gauge the impact of an unexpected and dreaded disease on the economies of affected nations (Nippani & Washer, 2004). The S.A.R.S. epidemic also involved a clear change in investors' risk level (Wong, 2008). Economists have long observed that societal responses to health risks tend to be extreme and inconsistent (Viscusi, 1989, 1990). It is important to address that the individual's responses to the S.A.R.S. outbreak were not only observed in the healthcare market (Bennett, Chiang & Malani, 2015) but also in the financial market. Several existing works explore the relationships between S.A.R.S. outbreak and stock returns. Chen, Jang, and Kim (2007) confirm that the tourism industry experienced the most serious damage in terms of stock price decline in the Taiwan Stock Exchange during the S.A.R.S. outbreak period. Chen, Chen, Tang, and Huang (2009) indicate that the S.A.R.S. crisis had some negative impacts on stock prices relating to the tourism, wholesale and retail sectors, but it impacted stock prices associated with the biotechnology sector positively. In addition, Ali, Md Nassir, Hassan, and Zainal Abidin (2010) show that the investors over-responded to the S.A.R.S. outbreak in terms of dramatic stock price decline in the Malaysian stock market. Hsieh (2013) finds that the stock prices are more volatile in the trading days during some crisis periods (such as the S.A.R.S. outbreak, 2002 anti-terrorist war periods, and the period of corporate governance stemming from the Enron scandal) than those during non-crisis periods. The findings obtained by Chen, Chen, and Lee (2013) indicate that the stock returns from the basic material industry in Hong Kong and from the service industry in the Philippines were influenced by local market sentiment due to the S.A.R.S. outbreak. The evidence generated by these empirical studies confirms that the investors would respond to the S.A.R.S. outbreak through the adjustment of stock prices in several Asian countries' stock markets.

Understanding the financial integration effects of the S.A.R.S. outbreak therefore might help to deal with the possible impacts on the economy and management of other infectious disease outbreaks. Because we expect S.A.R.S. or other epidemics of unknown origin might break out in the future, there should be a more comprehensive picture about the impact of the S.A.R.S. epidemic on financial integration. A study most closely related to this research is Nippani and Washer (2004), who use Mann–Whitney non-parametric tests

to examine the impact of the S.A.R.S. epidemic on the stock markets of Canada, China, Hong Kong, Indonesia, the Philippines, Singapore, Thailand, and Vietnam, and find that the S.A.R.S. epidemic had no negative impact on the affected countries' stock markets with the exception of China and Vietnam. Nevertheless, the results generated from their study may not be sufficient to fully address the effect of the S.A.R.S. epidemic on stock markets, because they neither incorporate the nature of the time-varying cointegration relation in their model specification, nor include the control group in their empirical analyses. Thus, this study applies the S.T.V.C. model coupled with the D.I.D. model in order to clarify the impact of the S.A.R.S. epidemic on the stock markets. Our study provides an important reference for investors who intend to diversify their portfolios for risk management during a severe epidemic outbreak.

3. Methodology

3.1. Time-varying cointegration analyses

In this study, we apply the S.T.V.C. model proposed by the Park and Hahn (1999) to investigate the time-varying market integration among the five Asian stock markets. The main advantages of the S.T.V.C. model against the conventional cointegration model are listed as follows: (1) The S.T.V.C. model specifies time-varying parameters and helps us to position the turning points of the estimated parameters on different unknown dates, providing us a better understanding on the transition of market integration. (2) The conventional cointegration approach only allows a constant long-run relation and usually rejects the existence of a cointegrating relation when structural changes of data are identified (Chen, Chang & Lin, 2014). When a time-varying cointegrating relation is detected by using the S.T.V.C. model, we can interpret it as a long-run relation, where the coefficients may help us to learn more about the mechanism of the economy behind them (Zuo & Park, 2011).

We now introduce the specification of the S.T.V.C. model as follows:

$$CA_{wj} = \beta_0 + \delta_w + \beta'_{wj}X_{wj} + \varepsilon_{wj} = \beta_0 + \delta_w + \beta_{1(wj)}HK_{wj} + \beta_{2(wj)}TW_{wj} + \beta_{3(wj)}SG_{wj} + +\beta_{4(wj)}JP_{wj} + \varepsilon_{wj}, \quad (1)$$

where subscript w denotes the week (=1, 2, 3…, W) and j denotes the year (=1, 2, 3,…, T); CA_{wj} is the aggregate stock price index in China; $X_{wj} = [HK_{wj}, TW_{wj}, SG_{wj}, JP_{wj}]$ represents a vector of the aggregate stock price indices in Hong Kong, Taiwan, Singapore, and Japan; β_0 denotes the constant term; ε_{wj} is the error term; δ_w denotes the fixed week effect to capture the seasonality presented in the long-run relation; $\beta_{m(wj)}$ ($m = 1, 2, 3, 4$) is a time-varying parameter corresponding to X_{wj}. Once the time-varying cointegration relation between these five Asian stock markets is confirmed, the estimated $\beta_{m(wj)}$ are indicators measuring the time-varying long-run relations between China and the other four Asian stock markets.

The model specification in Equation (1) not only simultaneously estimates the time-varying long-run relations between China and the other four Asian stock markets, but also prevents the rise of a type I error by using the specification of the S.T.V.C. model. Specifically, $\beta_{m(wj)} = \beta(t/n)$ is a smooth function defined on [0, 1], where n is the number of observations, and t is the order of observations in the total sample given by $t = W(j − 1) + w$. Using the Fourier flexible form function to approximate the time-varying parameter β_{wj}, Equation (1) can be expressed by:

$$CA_{wj} = \beta_0 + \delta_w + \lambda'_k X_{kwj} + \varepsilon_{kwj}, \tag{2}$$

where $\varepsilon_{kwj} = \varepsilon_{wj} + [\beta(t/n) - \beta_k(t/n)]X_{kwj}$, $X_{kwj} = f_k(t/n) \otimes X_{wj}$, $f_k = (1, \gamma, \eta'_1(\gamma), ..., \eta'_k(\gamma))'$ with $\gamma \in [0, 1]$, $\eta_i(\gamma) = (\cos 2\pi i\gamma, \sin 2\pi i\gamma)'$, $i = 1, 2, ... k$, and $\lambda_k = (\lambda'_{k,1}, \lambda'_{k,2}, ..., \lambda_{k,2(k+1)})'$. Here, $\otimes$ denotes the Kronecker product. The definitions of Y_{wj}, β_0, δ_w, X_{wj}, and ε_{wj} are the same as for Equation (1). Note that the standard ordinary least squares (O.L.S.) estimators of Equation (2) are asymptotically inefficient and standard limiting distributions (such as normal, χ^2, and F distributions) are not attainable, and hence we cannot obtain a valid inference based on the standard O.L.S. estimation (Park & Hahn, 1999).

In order to obtain a reliable inference for the time-varying parameters in Equation (2), Park and Hahn (1999) suggest the canonical cointegrating regression (C.C.R., hereafter) to estimate Equation (2). The C.C.R. estimator of β_k has been proven to be a consistent estimator of β, and its limit distribution is written by:

$$M^*_{nk} - 1/2(\prod(\hat{\beta}_k) - \prod(\beta)) \longrightarrow dN(0, \theta^2_* I_{2d}) \text{ as } n \to \infty, \tag{3}$$

where $\prod(\beta) = (\beta(\gamma_1)', ..., \beta(\gamma_d)')$; $\prod(\hat{\beta}_k) = (\beta(\gamma_1)', ..., \beta(\gamma_d)')$ for $\gamma_i \in [0, 1]$, $i = 1, 2, 3, ..., d$; n denotes total sample size; I_{2d} is a $2d \times 2d$ identifying matrix; M^*_{nk} is a $2d \times 2d$ matrix; and θ^2_* is the conditional long-run variance of the residuals from the transformed regression.

Park and Hahn (1999) derive two Wald-type variable addition tests to test the model specification of the S.T.V.C. model. The first specification test examines the null hypothesis of S.T.V.C. against the alternative hypothesis of the spurious regression with non-stationary errors, and its testing statistic is written as Equation (4):

$$\tau^* = \frac{RSS_{TVC} - RSS^s_{TVC}}{\theta^2_*}, \tag{4}$$

where RSS_{TVC} and RSS^s_{TVC} denote the sum of squared residuals from the C.C.R. estimation for Equation (2) and the same equation augmented with s additional superfluous regressors (such as time polynomial terms, $t, t2, t3, ..., t^s$), respectively. The limit distribution of τ^* is the χ^2 distribution with s degrees of freedom under the null hypothesis that the time-varying cointegration relation exists.

As for the second specification test, it is used to test for the null hypothesis of the fixed coefficient (FC) cointegration model against the alternative hypothesis of the S.T.V.C. model, and its testing statistic is written as Equation (5):

$$\tau^*_1 = \frac{RSS_{FC} - RSS^s_{FC}}{\theta^2_*}. \tag{5}$$

The limit distribution of τ^*_1 is also an χ^2 distribution where s degrees of freedom under the null hypothesis are true. If the model specification tests from Equations (4)-(5) validate the S.T.V.C. model, then the integration of the five selected Asian stock markets (based on the existence of time-varying cointegration relation) is verified during our study period. As a result, the long-run relation (measured by β_{wj} in Equation (1)) in aggregate stock price indices between China (the sourcing country) and each individual country could serve as

a measure for the magnitude of market integration between China (the sourcing country) and each individual country. Therefore, if the long-run relation (measured by β_{wj} in Equation (1)) is statistically significant, then we can conclude that the higher the absolute (or square) value is for the long-run time-varying relation (measured by β_{wj} in Equation (1)), the stronger the market integration is expected to be.

3.2. Difference-in-differences approach

Previous studies, such as Nippani and Washer (2004), exploring the effect of S.A.R.S. epidemic on financial markets belong to the so-called intervention analyses, in which the control group is omitted in the empirical analyses (Liu, 2006). The major drawback in such intervention analyses is that even when a significant impact of the S.A.R.S. epidemic on a financial market has been found, this finding may not provide any evidence suggesting that the impact was truly caused by the S.A.R.S. epidemic. In order to obtain an unambiguous inference, we include a control group into our investigation on the effect of the S.A.R.S. epidemic on regional market integration. Note that our selected Asian stock markets can be separated into three groups: the sourcing country (China), highly infected countries or areas (Hong Kong, Taiwan, and Singapore) and a minorly infected country (Japan). It is critical to note that the magnitude of time-varying cointegrating relations between China (the sourcing country) and the other four markets (highly infected and minorly infected countries) have been evaluated by the time-varying coefficients in the S.T.V.C. model. Thus, the time-varying relation between the China and Japan (minorly infected) stock markets is taken as a control group, while the time-varying relations in aggregate stock price indices between China and Hong Kong, Taiwan, and Singapore (highly infected) are included as the treatment group.

In the financial integration field, Ahrend and Goujard (2014) use the D.I.D. approach to examine whether the depth of cross-border financial integration may lead to asset price contagion. In order to evaluate the true effect of the S.A.R.S. epidemic on market integration, we specify the following panel-type D.I.D. model as follows:

$$y_{ti} = \beta_{kti} - \beta_{4ti} = \pi_i + \alpha_1 SARS_{ti} + \alpha_2 AFC_{ti} + \alpha_3 DCB_{ti} + \alpha_4 SMC_{ti} + \xi_{ti}, \qquad (6)$$

where β_{kti} (k = 1 (Hong Kong), 2 (Taiwan), 3 (Singapore)) represents the time-varying relation in aggregate stock price indices between the highly infected countries and China; β_{4ti} represents the time-varying relation in aggregate stock price indices between Japan (a minorly infected country) and China; $y_{ti} = \beta_{kti} - \beta_{4ti}$ is the difference of the estimated time-varying coefficients obtained from Equation (1); π_i is the fixed effect for individual country i (i = 1 (Hong Kong), 2 (Taiwan), 3 (Singapore). $SARS_{ti}$, AFC_{ti}, DCB_{ti}, and SMC_{ti} are dummy variables indicating the S.A.R.S. outbreak period (11/01/2002 to 08/07/2003), Asian financial crisis period (01/01/1998 to 06/25/1998), dotcom bubble crisis period (03/09/2000 to 04/26/2001), and subprime mortgage crisis period (08/09/2007 to 09/18/2008), respectively; α_h(h = 1, 2, 3, 4) are the parameters corresponding to $SARS_{ti}$, AFC_{ti}, DCB_{ti}, and SMC_{ti}, respectively; and ξ_{ti} denotes the error term.

Note that the estimated coefficient α_1 is the D.I.D. estimator originating from Ashenfelter (1978) and Ashenfelter and Card (1984). If estimated coefficient α_1 is not significantly different from zero, then it means that the influence of the S.A.R.S. epidemic on the long-run cointegrating relations in aggregate price indices between China and the other four Asian

stock markets are not significant within an integrated market (verified by two statistics, τ^* and τ_1^*, derived from the S.T.V.C. model). It follows that the insignificant estimated coefficient α_1 leads us to conclude that the S.A.R.S. epidemic could weaken the integration of our selected Asian stock markets under the condition that the cointegration relation in aggregate stock price indices is proved. Finally, if we define the dependent variable in Equation (6) as the time-varying relation in aggregate stock price indices between the four selected countries/areas and China (namely, $y_{ti} = \beta_{kti}$, $k = 1$ (Hong Kong), 2 (Taiwan), 3 (Singapore), 4 (Japan)), then Equation (6) becomes the panel type of the intervention model. We estimate both the D.I.D. and intervention models to show the true effect of the S.A.R.S. epidemic on the integration of our selected Asian stock markets.

4. Results

4.1. Data description

Data used in this study include weekly aggregate stock price indices from China, Hong Kong, Taiwan, Singapore, and Japan during the period 1998–2008, covering 5 years before and after the S.A.R.S. outbreak period (from 2002 to 2003) from the Datastream database, resulting in a total of 574 weekly observations. The 5-year interval before and after the S.A.R.S. outbreak period (from 2002 to 2003) was chosen because it is the duration frequently used to evaluate the effect of intervention on an epidemic disease (such as five-year survival rate, and remaining life years within a five-year age interval) in the epidemiology literature (Gordis, 2009). In addition, a simulation study conducted by Lee and MacKibbin (2004b) show that the real impacts of the temporary S.A.R.S. shock are negligible after 2008. These studies prove the validity of the target period selected (1998–2008) in this study to evaluate the effect of the S.A.R.S. epidemic on the integration of Asian stock markets.[1]

According to the W.H.O.'s S.A.R.S. epidemic report, probable S.A.R.S. cases with an onset of illness arose during the period 11/01/2002 to 08/07/2003. For 2003, China, Hong Kong, Taiwan, and Singapore contributed approximately 94% of total probable S.A.R.S. cases around the world (W.H.O.), but no S.A.R.S. deaths were reported in Japan. Therefore, China is the S.A.R.S. sourcing country; Hong Kong, Taiwan, and Singapore are grouped as highly infected countries (treatment group), and Japan is regarded as the minorly infected country (control group). In order justify the effect of the S.A.R.S. epidemic on the integration of these Asian stock markets, we further reorganise our time-varying cointegrating relations (measured by the estimated time-varying coefficients in the S.T.V.C. model) into the treatment group and the control group. The former group consists of the time-varying relations in aggregate stock price indices between the highly infected countries (Hong Kong, Taiwan, and Singapore) and China, while the latter group includes the time-varying relations in aggregate stock price indices between the minorly infected country (Japan) and China. We also create a S.A.R.S. outbreak dummy variable indicating the outbreak period from 11/01/2002 to 08/07/2003 and three dummy variables indicating three economic crisis periods (Asian financial crisis, 01/01/1998 to 06/25/1998; dotcom bubble crisis, 03/09/2000 to 04/26/2001; and subprime mortgage crisis, 08/09/2007 to 09/18/2008). The S.A.R.S. outbreak dummy variable identifies the true effect of the S.A.R.S. epidemic on the integration of the five Asian stock markets, and the other three dummy variables indicating three economic

crisis periods serve as control variables. Table 1 summarises the descriptive statistics for all variables used in this study, and Figure 1 displays the time plots of the aggregate stock price indices for the five Asian stock markets in Figure 1.

Table 1. Descriptive statistics.[a]

Variable in S.T.V.C.	Country	Mean	SD	Min	Max
Sourcing Country	China (CA)	398.12	204.25	215.34	1199.43
High Infection Group	Hong Kong (HK)	1525.35	540.55	686.04	3412.53
	Taiwan (TW)	238.035	59.04	127.98	426.52
	Singapore (SG)	531.69	211.39	228.84	1130.51
Low Infection Group	Japan (JP)	1031.00	240.78	605.67	1599.78
Variable in D.I.D.	Period	Mean	SD	Min	Max
S.A.R.S. Outbreak	11/07/2002–08/07/2003	0.07	0.25	0	1
Asian Financial Crisis	01/01/1998–06/25/1998	0.05	0.21	0	1
Dotcom Bubble	03/09/2000–04/26/2003	0.10	0.31	0	1
Subprime Mortgage Crisis	08/09/2007–09/18/2008	0.11	0.31	0	1

[a]We use dummy variables in D.I.D., such as during S.A.R.S. outbreak=1; 0 otherwise.
Source: Authors calculation.
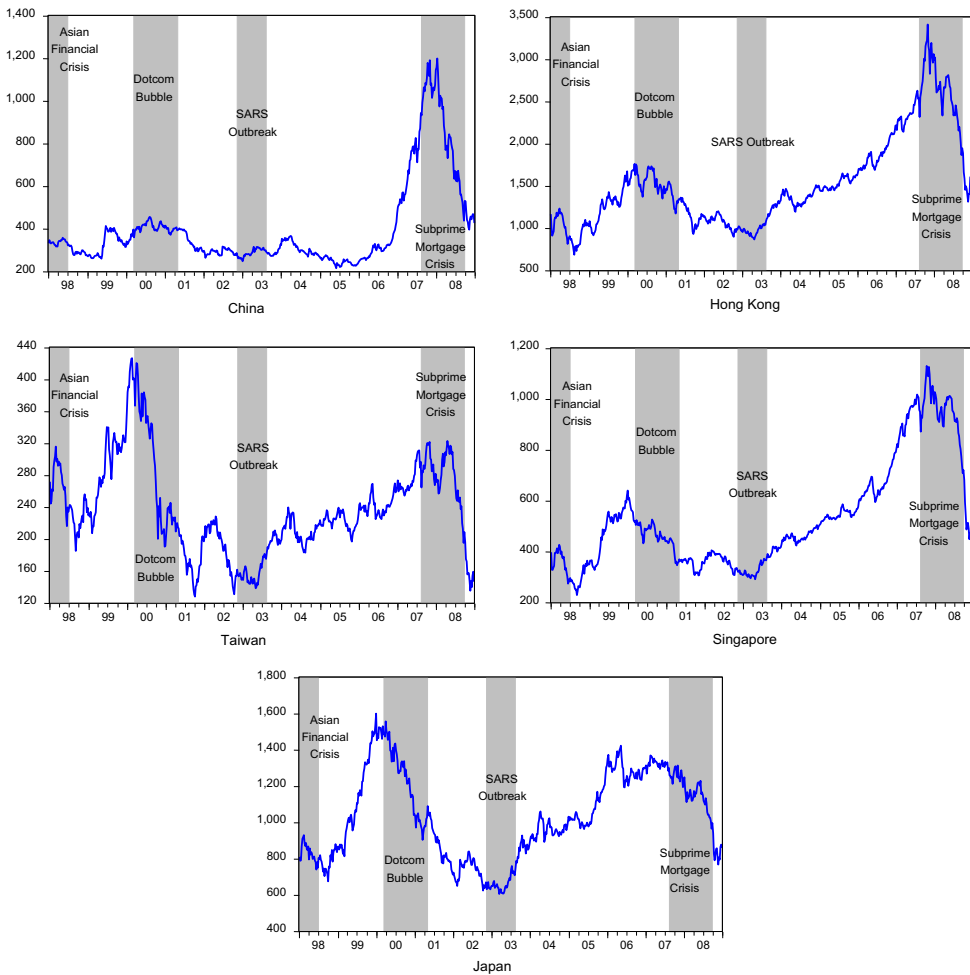
Figure 1. Aggregate price indices for the five Asian stock markets. Source: Authors calculation.

Table 2. A.D.F. unit root tests.[a]

	Demean		Detrend	
Country	Level	1st Diff	Level	1st Diff
China (CA)	−1.38	**−14.45**	−1.22	**−14.44**
Hong Kong (HK)	−1.36	**−23.47**	−1.51	**−23.46**
Taiwan (TW)	−1.77	**−24.35**	−1.45	**−24.34**
Singapore (SG)	−1.32	**−21.46**	−1.83	**−21.47**
Japan (JP)	−1.46	**−27.54**	−0.97	**−27.56**

[a]The optimal lags are chosen by the Schwarz information criterion to calculate the A.D.F. statistics. Bold fonts represent the 1% significance level.
Source: Authors calculation.

Table 3. Results for the S.T.V.C. model.

	H_0: Fixed Coefficient Cointegration Model H_A: S.T.V.C. Model	H_0: S.T.V.C. Model H_A: No Cointegration
Model Specification Test	τ_1^*	τ^*
Test Statistics	1442.37	1.39
1% Critical Values	13.28	13.28
5% Critical Values	9.49	9.49
10% Critical Values	7.78	7.78

Source: Authors calculation.

4.2. Time-varying cointegration

Table 2 presents the results for the Augmented Dickey-Fuller (A.D.F., hereafter) unit roots test for the aggregate stock price indices in five Asian countries. We find that the A.D.F. testing results for the aggregate stock price indices in our selected stock markets support the presence of unit roots no matter which demeaned or detrended time series data are used. Nevertheless, the A.D.F. testing results for the 1st differences of all aggregate stock price indices unambiguously suggest stationarity in the 1st differences of the time series data. These results confirm that all aggregate stock price indices used herein belong to I(1) series. We can therefore continue on with the time-varying cointegration analyses.

Table 3 displays results of the specification tests for the S.T.V.C. model. According to Park and Hahn (1999), four-order time polynomial terms (t, t^2, t^3, and t^4) can be considered as superfluous regressors to test whether or not the S.T.V.C. model fits the data well. As shown in Table 3, the test statistic (higher than the 1% critical value) rejects the null hypothesis of the fixed coefficient cointegration model in favour of the S.T.V.C. model. This result indicates that if there is a cointegration relationship in the aggregate stock price indices between China and other four Asian countries, then this relation should be modelled by a time-varying rather than a time-invariant way. In addition, the test statistic (lower than the 10% critical value) fails to reject the null hypothesis of the S.T.V.C. model. This finding gives solid evidence that the time-varying cointegration relation in the aggregate stock price indices between China and the other four countries does exist in our study period. Both specification tests validate our model specification posited in Section 3.1 and imply the existence of stock market integration between China and the four markets during 1998–2008.

In order to understand the long-run time-varying relations between China and each selected country, we plot the estimated coefficients from the S.T.V.C. model in Figure 2. The solid and dashed lines indicate the estimated time-varying coefficients and 95% confidence interval bands,

Table 4. Effect of the S.A.R.S. outbreak on market integration.[a]

	Intervention Model		Difference-in-differences Model	
	Dependent Variable=$\beta_{i,t}$		Dependent Variable=$\beta_{i,t}-\beta_{jp,t}$	
	Reference group=Japan		Reference group= Singapore	
	Coefficient	t-Statistic	Coefficient	t-Statistic
S.A.R.S. Outbreak	**−0.046**	**−3.68**	−0.020	−0.99
Asian Economic Crisis	**−0.190**	**−12.41**	**−0.571**	**−14.53**
Dotcom Bubble Crisis	**−0.079**	**−5.59**	**−0.242**	**−10.76**
Mortgage Loan Crisis	**−0.245**	**−11.63**	**−0.628**	**−11.32**
Hong Kong	**0.173**	**16.69**	**0.172**	**11.91**
Taiwan	**−0.135**	**−4.21**	**−0.136**	**−3.96**
Singapore	−0.031	−1.25	– –	– –
Constant	**0.119**	**12.48**	−0.032	−1.14
R^2	8.10%		15.52%	
Adjusted R^2	7.82%		15.23%	
Cross-section included	4		3	
Samples	2292		1719	

[a]White cross-section standard errors are used to calculate t statistics. Bold fonts represent the 1% significance level.
Source: Authors calculation.
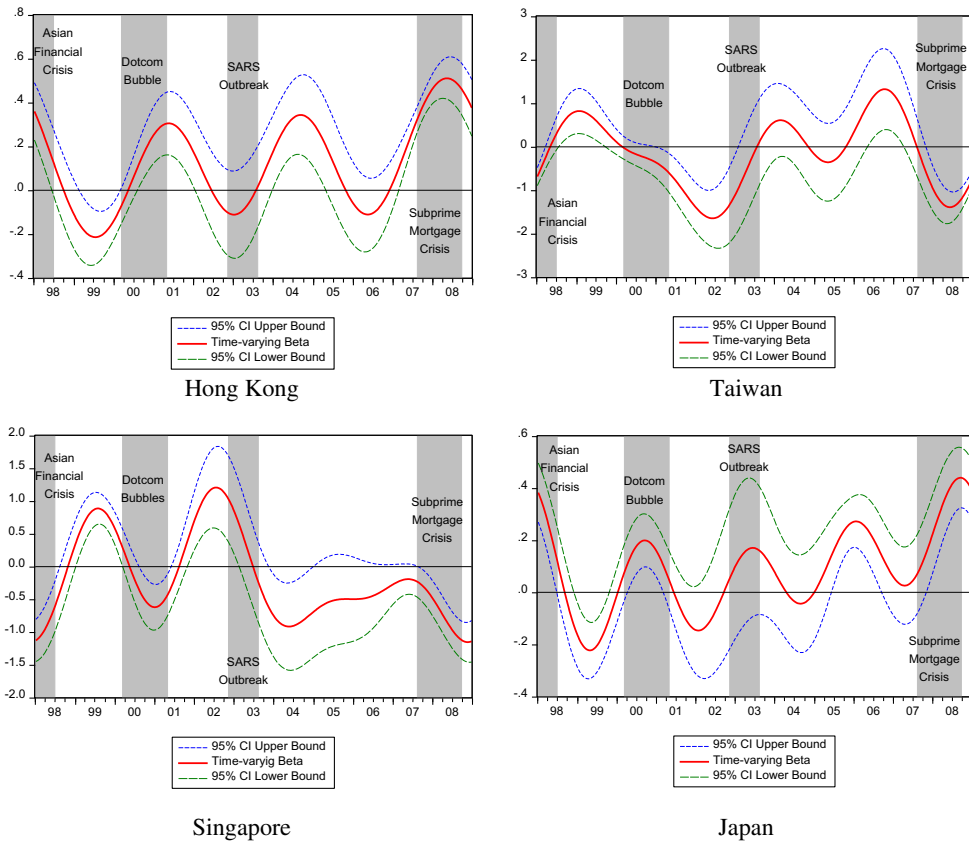
Figure 2. Time-varying coefficients in the cointegration Equation (1). Source: Authors calculation.

respectively. Figure 2 illustrates a change in the significance and relation in aggregate stock price indices between China and each selected country in the long run. However, the long-run relations in aggregate stock price indices between China and the other four countries are mostly likely

insignificant at the 5% significance level during the S.A.R.S. outbreak period. During the three economic crisis periods (Asian financial crisis, dotcom bubble crisis, and subprime mortgage crisis), we find significantly positive (negative) relations in aggregate stock price indices between Hong Kong and China (between Taiwan and China) and between Japan and China (between Singapore and China). Figure 2 and the estimated cointegration coefficients show that the integration relation between Hong Kong and China is greater during 2004–2005, while both Japan and Taiwan have larger integration relations with China during 2005–2006. These results imply that these sample countries have larger integration relationships with China during non-S.A.R.S. and non-crisis periods.

4.3. Difference-in-differences evaluation

In order to verify the true effect of the S.A.R.S. epidemic on the integration of stock markets, we report the results from the intervention and D.I.D. models in Table 4. It is important to address that the dependent variables in both the intervention and D.I.D. models are the estimated coefficients obtained from the S.T.V.C. model. As Figure 2 indicates, some of these estimated coefficients are not significant during some periods. Thus, we assign these insignificant coefficients to be zero when we estimate the intervention and D.I.D. models. In Table 4 the first two columns summarise the estimated results of the intervention model, while the last two columns display the estimated results of the D.I.D. model.

For the results of the intervention model, we find that the estimated coefficients of country-specific dummy variables are significantly positive and negative in Hong Kong and Taiwan, respectively. The former result suggests that the long-run relation in aggregate stock price indices between the Hong Kong and China stock markets is higher than that between the Japan and China stock markets. The latter result shows that the long-run relation in aggregate stock price indices between the Taiwan and China stock markets is lower than that between the Japan and China stock markets. Due to the insignificant estimated coefficient of the Singapore dummy variable, the long-run relation in aggregate stock price indices between the Singapore and China stock markets is indifferent from that between the Japan and China stock markets.

Both the S.A.R.S. outbreak and the three economic crisis dummy variables are significant at the 1% level after controlling the fixed effect of each individual country. Although the significant results of the three economic crises may reflect the fact that these economic crises generated significant effects on the integration of stock markets, the significantly negative coefficient in the S.A.R.S. outbreak dummy variable does not provide sufficient evidence for a significant effect of the S.A.R.S. epidemic on the integration of stock markets. In addition, the absolute values of the estimated coefficients of the three economic crisis dummy variables are much higher than that in the estimated coefficient of the S.A.R.S. outbreak dummy variable, which may not suggest that the three economic crises had a stronger impact on the integration of stock markets than the S.A.R.S. epidemic due to the different time spans impacting the stock markets. This is a common limitation in pre-post event evaluation studies without any control groups.

In contrast to the intervention model without any control for possible heterogeneities between minorly infected and highly infected countries, we now look at the results from the D.I.D. model incorporating the control groups in the empirical model. In the second line of Table 4, the signs of the estimated coefficients in the D.I.D. model are the same as

those in the intervention model. Nevertheless, we find that the estimated S.A.R.S. outbreak dummy variable becomes insignificant from zero after incorporating the control groups in the empirical model. This result together with the existence of stock market integration in these five Asian countries/areas (identified by the two statistics (τ^* and τ_1^*) from Equations (4)-(5)) implies that the S.A.R.S. epidemic attenuated the long-run relations in aggregate stock price indices between China and the other four Asian stock market. Therefore, we conclude that the S.A.R.S. epidemic likely did weaken the integration of our five selected Asian stock markets.

The significantly negative signs in the three estimated economic crisis dummy variables indicate that the difference in the estimated time-varying coefficients between highly infected countries (Hong Kong, Taiwan, and Singapore) and minorly infected country (Japan) is lower during the economic crisis periods than those during other periods. If we define the difference in the estimated time-varying coefficients between highly infected countries and minorly infected country as the relative long-run relation between highly infected countries and China, then the significantly negative signs in the three estimated economic crisis dummy variables suggest that the economic crises did reduce the relative long-run relation between the highly infected countries and China. We are uncertain whether or not Japan could serve as a good control for those countries impacted by these three economic crises. Our findings in the estimated economic crisis dummy variables do not support that the economic crises could weaken the integration of the stock markets of the five Asian countries, but do reveal that the economic crises should be controlled for when evaluating the effect of S.A.R.S. on the integration of the five Asian stock markets. Finally, using the same arguments to interpret the results in the estimated economic crisis dummy variables, the significant results in the estimated coefficients of the Hong Kong and Taiwan dummy variables suggest the importance of including country-specific dummy variables in order to justify the impact of S.A.R.S. on the integration of stock markets among the five Asian countries.

4.4. Implications

The empirical results presented herein have several practical implications. First, we find that the S.A.R.S. epidemic did attenuate the stock market integration among the five Asian countries (Hong Kong, Taiwan, Singapore, Japan, and China), which might imply more gains from portfolio diversification during an epidemic outbreak period. In other words, investors will experience less difficulty in reaping gains from asset diversification across these sample countries during the S.A.R.S. period compared with during the economic crises. Second, the main results have important implications for investors, managers, and policymakers interested in multinational investment. For investors, reduced stock market integration increases opportunities for international portfolio diversification. For policymakers, increased integration during economic crises may curtail national governments' ability to design appropriate stabilisation policies (Martins & Gabriel, 2014). For financial academia, this study expands the financial integration issue to a cross-field study.

This article is a unique contribution to the limited literature on severe disease and financial cointegration in three aspects. First, no study has explored the dynamics of cointegration caused by a severe epidemic disease, which has now become an important issue in the

real economy and human health due to the recent outbreaks of Zika, Ebola, and M.E.R.S. Moreover, this study compares the integration impact of S.A.R.S. with three economic crises. The results in this regard are novel. Second, it is intuitive that financial market integration changes with economic conditions (Kim et al., 2006). For this reason, recent studies have allowed integration to vary over time and with events (e.g., Aggarwal, Lucey & Muckley, 2003; Barr & Priestley, 2004). Changes over the sample period might yield some substantial influences over the causal relationships considered, and for this reason the links between sourcing country and other sample countries might follow the same patterns of sensitivity as described by Thoma (1994) and Swanson (1998). The S.T.V.C. test used herein allows for more flexibility in studying the dynamics of market integration and may help to shed light on expanding the findings of market integration. Third, it has been claimed that controlling for selection on observable factors may not be sufficient, since the remaining unobservable differences may still lead to a biased estimation of treatment effects (Swamy, 2014). Incorporating the D.I.D. approach with the control group has the potential to significantly improve the quality of non-experimental evaluation results in terms of eliminating unobserved time-invariant differences in stock market integration between minorly infected and highly infected countries, thus avoiding any omitted-variable biases.

Financial integration tends to be thought of as a mechanism to smooth shocks (Loutskina & Strahan, 2015). On the other hand, financial segmentation implies some heterogeneity in investment opportunity sets across countries – a feature that makes the pricing of assets more complicated, because asset prices and the endogenous cross-sectional wealth distribution must be jointly determined (Bhamra, Coeurdacier & Guibaud, 2014). A low level of financial integration tends to produce an inefficient international risk-sharing environment (Donadelli & Paradiso, 2014). In this paper we show that financial integration did attenuate during the S.A.R.S. epidemic in contrast to the possible influence of economic crises on stock market integration (Hemche et al., 2016; Narayan et al., 2014). In addition, Lence and Falk (2005, p. 889) mention that the issue of whether asset prices are cointegrated or not rests on the characteristics of preferences and endowment processes, not on market integration and /or market efficiency. Therefore, we do not discuss the issues of market integration and/or market efficiency. Further research efforts could either eliminate some of the limitations or expand the scope of investigation in this study. First, a further study could, for example, empirically test whether the numbers of infected cases and deaths influenced the market integrations. According to Ho et al. (2013), the influence of an aviation disaster on the post-crash equity value of airlines, both crash and non-crash companies, is closely related to the level of fatality involved. Our findings might result from a higher degree of fatality having a larger and more persistent negative impact on the stock prices during the outbreak. The number of deaths for Hong Kong, Taiwan, and Singapore were 300, 180, and 33, respectively. However, some data are absent about the S.A.R.S. weekly numbers of infected cases and deaths. Second, Guerin (2006) pinpoints that geographical factors, proxying for information costs, may determine the financial integration with the world economy. The distances in miles from Guangdong Province, China to the capital cities of the infected areas of Hong Kong, Taiwan, and Singapore are 441, 690, and 1895, respectively. In other words, the mechanisms and theories related to the various responses of financial cointegration can be further researched.

5. Conclusion

Using weekly aggregate stock price indices from the S.A.R.S. sourcing country (China), highly infected countries (Hong Kong, Taiwan, and Singapore), and a minorly infected country (Japan) during the period 1998–2008, this study investigates the impact of the S.A.R.S. epidemic on stock market integration based on the extreme value theory. To this end, we first estimated the smooth time-varying cointegration model to verify the existence of the time-varying cointegration relation among these Asian stock markets and then used the difference-in-differences approach to evaluate whether or not the S.A.R.S. epidemic impacted the long-run relationship between China and the other four Asian stock markets. Our results support the existence of the time-varying cointegration relation in the aggregate stock price indices between China and the other four Asian countries during our study period, and the S.A.R.S. epidemic did weaken the long-run relationship between China and these four markets. The important implication generated from our findings is that the S.A.R.S. epidemic created some heterogeneity in investment opportunity and produced an inefficient international risk-sharing environment. Thus, investors could have achieved arbitrage profits through portfolio diversification among these five Asian countries in the event of catastrophic epidemic diseases.

Note

1. In order to show the robustness of our results, we also conduct brief sensitivities analyses using the weekly data covering the period from the first week of 1998 to the last week of 2015. In general, the results obtained from the sensitivities analyses are the same as those we present in the current study. Due to the space limitation, we did not report these results but they are available upon request to the authors.

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Disclosure statement

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