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**Mean Reversion in Asia-Pacific Stock Prices:
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Mean Reversion in Asia-Pacific Stock Prices: New Evidence from Quantile Unit Root Tests

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Abstract: We investigate the stationarity of real stock prices among 12 Asia-Pacific countries over the period 1991–2018. The methodology employed is driven by the need to address three key concerns: (i) the identification of which positive or negative shocks are linked to stationarity; (ii) the identification of different speeds of adjustment towards long-run equilibrium; and (iii) the identification of mean reversion and potential asymmetric speed of adjustment before and after the 2008-2009 global financial crisis. To meet these concerns, we examine the time series properties of the data within a quantile unit root testing framework. Our results generally indicate that real stock prices are stationary at the upper quantiles only. There is also evidence of a varied speed of adjustment process across the quantiles where stationarity is present. Further analysis indicates that real stock prices became much more reverting and with a faster speed of adjustment after the global financial crisis, except for Japan and New Zealand.

Keywords: Stock prices, Mean reversion, Quantile unit root regression

JEL Classifications: C1, C5, G1

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1. Introduction

Do stock market prices follow a random walk or a mean-reverting process? This basic question, posed by Fama (1970) nearly 50 year ago, and since labeled as the Efficient Market Hypothesis or EMH, remains at the core of a continuing debate among economists and finance researchers. The EMH states that a market is efficient if prices at any point in time always fully reflect all available information. The weak-form efficiency variant of the EMH which presumes that future returns cannot be predicted based on past information is the most frequently examined in the literature. From an empirical perspective, the basic question posed by the EMH is one that, at least in principle, should be relatively easy to answer. Yet the EMH continues to receive considerable attention (see, for example, Narayan and Smyth (2005), Lean and Smyth (2007), Lim et al. (2008), Lee et al. (2010), Lee et al. (2014), Shen and Holmes (2014a), Wang et al. (2015), among others).

There are at least two reasons for continued interest in the EMH. First, as suggested by Bose (2005), the implications of the close link between the stock market and the real economy are fundamentally important in formulating economic policies. Mauro (2003, p. 131), writing in the context of emerging economies, made this point concisely: “Given the speed with which stock market prices become available, it seems that the stock market could be a helpful leading indicator in forecasting economic growth. Moreover, if one were to find that stock price changes that are not justified by fundamentals do really affect output, this would raise a number of policy issues that would be particularly relevant for emerging markets.”

Another reason for the sustained interest in this topic is that the fundamental question suggested by the EMH is naturally an empirical one; it is simply impossible to answer at some point without turning to data. Perhaps not surprisingly, it seems the answer to the empirical question posed by the EMH hinges on appropriate specification of the dynamic behavior of stock prices. Empirical work on this topic argued that the behavior of stock prices is driven by

nonlinearities that can be attributed to institutional constraints, market frictions and transaction costs. Relevant examples include Lim and Liew (2007), Chen and Kim (2011), Lee et al. (2014), and Shen and Holmes (2014b), though the evidence is still mixed at best. Tests for mean reversion of stock prices typically boiled down to an examination of the sign and significance of the estimated autoregression coefficient, depending on whether large negative shocks have potentially different impacts from large positive shocks. Of course many researchers recognized that the presence of structural breaks might also explain the nonlinearity of stock prices (Narayan et al. 2013; Shen and Holmes, 2014a). Early work on this research area tended to support the conjecture that structural breaks based on financial crisis and other critical economic events lead to regime shifts in stock price dynamics.

While considerable progress has been made in examining the mean reversion of stock prices, there is scope for additional work. Research on this topic has yet to consider the question of whether stationarity of stock prices is associated with positive or negative shocks. Previous research has considered only the case of the constant speed of stock price adjustment towards its equilibrium with a conditional mean function. A more complete analysis would examine mean reversion of stock prices that accounts for potential asymmetry and different speed of adjustment towards long-run equilibrium for various signs and sizes of shocks affecting stock prices.

Additionally, the 2008-2009 global financial crisis, GFC henceforth, has renewed the concern about stock market inefficiency in emerging market economies. As noted by Lim and Brooks (2011), stock market inefficiency could arise due to the existence of a financial crisis because investors generally panic during this critical economic event, adversely affecting their ability to price stocks efficiently. There is still a dearth of research on the impact of the GFC on the mean reversion of stock prices. Among a very few studies, Anagnostidis et al. (2016) have considered explicitly the effect of the GFC on the efficiency of Eurozone stock markets. They

did so by using the Generalized Hurst Exponent method and found significant mean reversion of stock prices in 12 Eurozone countries. Moreover, applying a Markov regime-switching unit root test for 12 Asia-Pacific countries, Shen and Holmes (2014a) found that the aftermath of the GFC is more likely associated with a much faster speed of adjustment of real stock prices towards a long-run equilibrium. Although they showed that real stock prices are mean-reverting in both stationary and non-stationary regimes, their approach is restricted to a certain number of regimes. Therefore, further testing of stock price mean reversion that accounts for the possibility that shocks of different sign and magnitude have different impact on stock prices is called for.

This paper attempts to fill these gaps by examining the different behavior of real stock prices for 12 Asia-Pacific countries in a quantile unit root testing framework. An investigation of the dynamic behavior of real stock prices using this sample of countries is worthwhile because their economic importance in the region has increased substantially in recent years. The contribution of this paper is twofold. First, it suggests an alternative method to test for mean reversion of real stock prices. In contrast to the related literature, in which the specific number of regimes is restricted, this paper incorporates the differences in the transmission of all kinds of different shocks using an adaptation of the quantile unit root testing proposed by Koenker and Xiao (2004). The test is conducted in order to verify if mean reversion is affected by the nature of shocks hitting real stock prices. That is, we aim to verify if there is asymmetric speed of adjustment towards long-run equilibrium for positive or negative shocks. The quantile unit root test allows us to examine the effect of shocks of different signs and magnitudes on real stock prices. This is in contrast to the conventional unit root tests, which provides only a single test statistic capturing the constant speed of adjustment with a conditional mean function (see, for example, Tsong and Lee, 2011). Moreover, the quantile unit root test reduces estimation

uncertainty by avoiding the estimation of additional regime parameters (Hosseinkouchack and Wolters, 2013).

The second contribution is that the examination of stationarity of real stock prices before and after the GFC adds to the literature on stock price behavior around periods of market turmoil especially during the recovery phase. As noted by Anagnostidis et. al. (2016), taking into account the impact of the GFC and its aftermath provides a suitable framework for investigating stock market efficiency. This is of potential interest to policy makers because the stabilization of financial policies could be different before and after the GFC. If exogenous shocks to stock prices are temporary, particularly during the crisis, then the stabilization of financial policies will not have permanent effects (Lee et al., 2014). In addition, a further elaboration on the link between the dynamic behavior of stock prices and the GFC would help investors predict future movements in stock prices more accurately.

The rest of the paper is organized as follows: Section 2 provides a discussion of the most recent studies of stock price mean reversion; Section 3 discusses the quantile unit root test that we employ and the data; Section 4 discusses the empirical results and Section 5 presents the conclusions and policy implications.

2. Literature review

The dynamic behavior of stock prices has been the subject of a burgeoning literature. One variant of this literature provides explanations for mean reversion in stock prices. These include, among others, the stock market overreaction hypothesis (De Bondt and Thaler, 1985; Shefrin and Statman, 1985), which states that stock prices have temporary swings away from their fundamental value due to optimism and pessimism; irrational behavior of noise traders (Poterba and Summers, 1988); and stock market size and associated risk factors (Zarowin, 1990; Richards, 1997). Summers (1986) emphasized that the mean reversion in stock prices can be

observed if the expected returns are mean-reverting (Wang et al., 2015). This is because expected return is a function of the stock value under the assumption that all available information is incorporated into stock prices, which suggests that mean reversion does not necessarily contradict market efficiency (Fama and French, 1988). Conrad and Kaul (1993) explain that price-related microstructure-induced biases affect the specification of expected returns of low-priced stocks. Moreover, Chan (1988) and Ball and Kothari (1989) argue that variation in relative risk leads to negative serial correlation in relative returns which has a direct impact on expected relative returns.

Most of the studies of the weak-form EHM concerning Asia-Pacific countries have employed methodologies based on different unit root tests to investigate stationarity of stock prices. Some examples of studies that have utilized linear univariate unit root tests include Chaudhuri and Wu (2003), Groenewold et al. (2003), Narayan and Symth (2004), Phengpis (2006), Narayan and Symth (2007) and Setianto and Mannap (2011). On the other hand nonlinear univariate unit root tests are employed in Lim and Liew (2007), Qian et al. (2008), Munir and Mansur (2009), Tan et al. (2010), Chen and Kim (2011), Mishra and Mishra (2011), Gozbasi et al. (2014), Rizvi and Arshad (2016). However, the univariate unit root tests are criticized due to low power. To address this issue, some studies used panel-type unit root tests, including Narayan and Symth (2005, 2007, 2008), Ahmad et al. (2010), Lee et al. (2010), Shen and Holmes (2014b) and Lee et al. (2014). Other approaches have addressed structural breaks using panel data such as Lee et al. (2010), Lu et al. (2010), Shen and Holmes (2014b) and Lee et al. (2014), and using time-series data such as Chaudhuri and Wu (2004), Mishra et al. (2015) and Wang et al. (2015). Irrespective of which tests are considered, the results are mixed as to whether or not stock prices are stationary.

A few studies exist on the effect of financial crises on stock market efficiency. Some examples of empirical investigations that focused on the impact of the 1997 Asian Financial

crisis include Hoque et al. (2007), Lim et al. (2008) and Kim and Shamsuddin (2008). In terms of the impact of the GFC, however, previous studies have focused on European Union stock markets. Examples of these studies include Horta et al. (2014), Smith (2012), Katris and Daskalaki (2013), Sensoy and Tabak (2015) and Anagnostidis et al. (2016).

Shen and Holmes (2014a) examine on the impact of the GFC on the mean reversion of stock prices for a sample of 12 Asia-Pacific countries using the Markov switching-regime approach and find that the GFC is associated with a shift in regimes with a faster speed of mean reversion. They argue that a single test statistic based on the single-regime ADF test covering the entire study period is inadequate in explaining the differences in the behavior of stock prices before and after the GFC. This has implications both for model-building and for statistical testing. In contrast to Shen and Holmes (2014a), the present study allows for the presence of transmission of all kinds of different shocks. In the search for weak-form EMH that does not restrict the analysis to a specific number of regimes, the most fruitful approach has been one where allowance is made for the possibility that shocks of different signs and magnitudes have different impacts on the behavior of real stock prices.

This is the first study that examines the behavior of stock prices in the Asia-Pacific region within a quantile unit root testing framework. In contrast to the above studies of asymmetries and nonlinearities, the methodology employed here enables us to not only test the null of non-stationarity across quantiles, but also to compare and contrast speeds of adjustment of stock prices towards to its long-run equilibrium level across quantiles. In addition to this, such an approach allows the measurement of local persistence and distinguishes globally between nonstationarity and mean reversion. Existing studies of Asia-Pacific stock price behavior only identifies a stationary (nonstationary) process in a specific number of regimes, which ignores valuable insights into quantile-varying behavior of stock prices.

3. Methods and data

3.1 Quantile unit root test

This section outlines the quantile unit root testing method that is used for our empirical work. The test, developed by Koenker and Xiao (2004), has improved power because the potential heavy-tailed behavior in the data and magnitudes of shocks that are endogenously determined by the data are incorporated into the testing framework.

The conventional approach to assess the unit root properties of real stock prices is the ADF regression model with q lags. Let s_t denote the natural logs of the monthly real stock prices for a given country i and ε_t denote a white noise residual. The ADF regression of log real stock prices with a drift ρ_0 can be performed via the OLS estimation of

$$\Delta s_t = \rho_0 + \rho_1 s_{t-1} + \sum_{i=1}^q \gamma_i \Delta s_{t-i} + \varepsilon_t \quad (1)$$

where ρ_1 is the autoregression (AR) coefficient. The real stock price process contains a unit root, and hence nonstationary if $\rho_1 = 0$. The condition for stationary properties of real stock prices and for ruling out explosive behavior is where $-2 < \rho_1 < 0$. Following Koenker and Xiao (2004), we define the τ th conditional quantile of Δs_t as:

$$Q_{\Delta s_t}(\tau | \Gamma_{t-1}) = \rho_0(\tau) + \rho_1(\tau) s_{t-1} + \sum_{i=1}^q \gamma_i(\tau) \Delta s_{t-i} + \varepsilon_t. \quad (2)$$

where $Q_{\Delta s_t}(\tau | \Gamma_{t-1})$ is τ th quantile of Δs_t conditional on the past information set, Γ_{t-1} . In Equation (2), the τ th conditional quantile of $\Delta \pi_t$ is denoted by $\rho_0(\tau)$, which measures the average size of shock hitting real stock prices in each quantile (Tsong and Lee, 2011). $\rho_1(\tau)$ measures the speed of mean reversion of $\Delta \pi_t$ within each quantile. The estimates for $\rho_1(\tau)$ can be used in approximating the half-lives (HL) for any monotonic stationary real stock price process in each quantile through the formula $HL = \ln(0.5) / \ln(\hat{\rho}_1(\tau) + 1)$. The HL can be

approximated when the null hypothesis of $\rho_1(\tau) = 0$ is rejected; otherwise, half-lives are set to be infinite. The optimal lag length is chosen according to the Akaike Information Criteria (AIC).

The coefficients $\rho_0(\tau)$, $\rho_1(\tau)$ and $\gamma_i(\tau)$ are estimated by minimizing the sum of asymmetrically weighted absolute deviations:

$$\min \sum_{t=1}^n \left(\tau - I \left(s_t < \rho_0(\tau) + \rho_1(\tau)s_{t-1} + \sum_{i=1}^q \gamma_i(\tau)\Delta\pi_{t-i} \right) \right) \left| s_t - \rho_0(\tau) + \rho_1(\tau)s_{t-1} + \sum_{i=1}^q \gamma_i(\tau)\Delta s_{t-i} \right| \quad (3)$$

where $I = 1$ if $s_t < \left(\rho_0(\tau) + \rho_1(\tau)s_{t-1} + \sum_{i=1}^q \gamma_i(\tau)\Delta s_{t-i} \right)$ and $I = 0$, otherwise.

Given the solution for $\hat{\rho}(\tau)$ from Equation (3), the stochastic properties of Δs_t within the τ th quantile can be tested using the t -ratio statistic proposed by Koenker and Xiao (2004) as follows:

$$t_n(\tau) = \frac{f(\widehat{F^{-1}(\tau)})}{\sqrt{\tau(1-\tau)}} (s'_{-1} M_Z s_{-1})^{1/2} (\hat{\rho}(\tau) - 1) \quad (4)$$

where s_{-1} is the vector of lagged real stock prices and M_Z is the projection matrix onto the space orthogonal to $Z = (1, \Delta s_{t-1}, \dots, \Delta s_{t-q})$. The consistent estimator of $f(F^{-1}(\tau))$ is $f(\widehat{F^{-1}(\tau)})$, with f and F denoting the probability and cumulative density functions of ε_t in Equation (2). To estimate $f(F^{-1}(\tau))$, Koenker and Xiao (2004) proposed the following rule:

$$f(\widehat{F^{-1}(\tau)}) = \frac{(\tau_i - \tau_{i-1})}{x'(\hat{\rho}(\tau_i) - \hat{\rho}(\tau_{i-1}))} \quad (5)$$

with $\tau_i \in \Gamma$. As shown in the empirical analysis below, we select $\Gamma = \{0.1, 0.2, \dots, 0.9\}$. The use of $t_n(\tau)$ statistic allows us to test the unit root hypothesis in each quantile. To be specific, this allows us to examine both the dynamics of real stock prices and the possibility of different mean reverting behavior when the series is hit by various sizes and signs of shock across a range of quantiles. The ADF and other unit root tests that only concentrate on the conditional central tendency of the series behavior do not permit an elaboration of such behavior.

To obtain a more complete inference of the unit root behavior across quantiles, Koenker and Xiao (2004) proposed the quantile Kolmogorov-Smirnov (QKS) test as follows:

$$\text{QKS} = \sup |t_n(\tau)| \quad (6)$$

We construct the QKS statistics by taking the maximum $|t_n(\tau)|$ statistics at $\tau_i \in \Gamma$. The QKS test provides a general perspective of the behavior of real stock prices and insights into global persistence. For example, if the shocks to real stock prices are short and long-lived in small and large quantiles, respectively, the QKS test means that the stationary behavior of the series in the low quantiles facilitates the whole process to revert to the series' steady-state level. The QKS test also indicates that real stock prices might change for a short period of time at various sizes of shocks that hit the series but unlikely to deviate from its steady-state level even when a positive shock such as a financial boom increases real stock prices.

Note that the limiting distributions of $t_n(\tau)$ and QKS test statistics are non-standard. In this study, the resampling procedure recommended by Koenker and Xiao (2004) is used to approximate the small-sample distributions of $t_n(\tau)$ and the QKS tests even though their limiting distributions are nonstandard. Following Koenker and Xiao (2004), this resampling procedure is outlined below:

1. Regress the q -order autoregression $\Delta s_t = \sum_{i=1}^q \hat{\gamma}_i \Delta s_{t-i} + \hat{\varepsilon}_t$ by ordinary least squares (OLS) and obtain estimates $\hat{\gamma}_i$ for $i = 1, 2, \dots, q$, and the residuals $\hat{\varepsilon}_t$.
2. Draw a bootstrap sample of ε_t^* with replacement from the empirical distribution of the centered residuals $\bar{\varepsilon}_t = \hat{\varepsilon}_t - (n - q)^{-1} \sum_{t=q+1}^n \hat{\varepsilon}_t$.
3. Generate the bootstrap sample of Δs_t^* recursively using the fitted autoregression $\Delta s_t^* = \sum_{i=1}^q \hat{\gamma}_i \Delta s_{t-i}^* + \hat{\varepsilon}_t^*$, with $\hat{\gamma}$ denoting the OLS estimates in step (1), and starting values $\Delta s_i^* = \Delta s_i$ for $i = 1, 2, \dots, q$.
4. Obtain the bootstrap sample of s_t^* based on $s_t^* = s_{t-1}^* + \Delta s_t^*$ with $s_1^* = s_1$.

5. With the resample s_t^* , compute the bootstrap counterparts of $\hat{\rho}_0(\tau)$, $\hat{\rho}_1(\tau)$, the $t_n(\tau)$ and the QKS test, denoted by $\hat{\rho}_0^*(\tau)$, $\hat{\rho}_1^*(\tau)$, $t_n^*(\tau)$ and QKS^* , respectively.
6. Repeat Steps 2 to 5 with 5000 bootstrap replications in this study.
7. Calculate the empirical distribution function of the 5000 bootstrap values of $\hat{\rho}_0^*(\tau)$, $\hat{\rho}_1^*(\tau)$, $t_n^*(\tau)$ and QKS^* tests, and use these empirical distribution functions as an approximation of the cumulative distribution of the respective tests under the null.
8. Using the bootstrap p -value to make inference.

3.2 Data

We use monthly data on the natural logarithm of real stock price expressed in local currencies with the base year 2010 = 100 for each of the 12 Asia-Pacific countries. The data are obtained from the *International Financial Statistics*. Noting that different results can be obtained using different indices, we use the market value-weighted index, consistent with the existing literature. In this study, we are interested in testing for a mean reversion model based on a long sample period consistent with the suggestion of Akarim and Sevim (2013). Hence, we focus on the time-span of the data instead of frequency and use monthly data over the period 1991:M1 to 2018:M8. Figure 1 plots real stock prices for each country in our sample which include Australia, China, Hong Kong, Indonesia, Japan, Malaysia, New Zealand, the Philippines, Singapore, South Korea, Taiwan and Thailand. The series exhibit mixed trends though it also shows that real stock prices noticeably declined during the 2008-2009 period which includes the global financial crisis.

INSERT FIGURE 1 HERE

Table 1 presents the mean, standard deviation, skewness, kurtosis, and Jarque-Bera (JB) normality test statistic for monthly real stock prices. Thailand and Malaysia have respectively

the most and least variability based on sample standard deviations. It is noticeable that the JB test rejects the null hypothesis of normality with very low p -values for all countries, indicating that real stock prices exhibit fat tails and non-normality. The significant evidence of non-normality in Table 1 lend credence to the application of quantile unit root testing for capturing real stock price dynamics in our sample of Asia-Pacific countries.

INSERT TABLE 1 HERE

4. Empirical results

4.1 Univariate unit root tests results

We begin with univariate unit root or stationary tests such as ADF, Elliot et al. (1996, DF-GLS), Phillips and Perron (1988, PP), Ng and Perron (2001, NP), and Kwiatkowski (1992, KPSS) tests. The ADF, DF-GLS, PP and NP tests are of a unit root null, while the KPSS test is of a stationary null. These univariate unit root regressions are estimated both with and without a time trend. The results are reported in Table 2. The optimal lag is determined using Akaike Information Criteria (AIC) for the ADF and DF-GLS tests. As suggested by Newey and West (1987), we choose bandwidth by the Barlett Kernel for the KPSS, PP and NP tests.

The ADF, DF-GLS and PP tests without a time trend reject the unit root null consistently only for the three countries of Malaysia, Singapore and Taiwan at the 10% significance level or better. The ADF and DF-GLS tests further reject the unit root null at the 10% significance level for China and Thailand, respectively. The NP test without a time trend rejects the unit root null only for Taiwan and Singapore respectively at the 5% and 10% significance levels. With a time trend, the four univariate unit root tests that we consider consistently reject the unit root null at the 5% significance level or better for only the four countries, China, Hong Kong, Malaysia and Taiwan. The ADF and DF-GLS tests also reject the unit root null at the 10% significance level for South Korea and Japan, respectively. For the KPSS test without at time trend, the stationary

null is not rejected only for New Zealand and Taiwan. The KPSS test with a time trend fails to reject the stationary null only for China, Hong Kong, Malaysia and Thailand.

In sum, the univariate tests either reject the unit root null or cannot reject the stationary null for only a handful of our sample countries which suggests that for the majority of our sample countries, stock prices are non-stationary. Accounting for a deterministic trend does not alter this conclusion. Therefore, the univariate test results imply that stock prices in our sample countries in general do not exhibit mean reversion but instead follow a random walk consistent with the efficient market hypothesis. These results are in line with previous studies such as Shen and Holmes (2014) for China and Taiwan, Wang et al. (2015) for China, Japan and Hong Kong, among others.

INSERT TABLE 2 HERE

4.2 Quantile unit root test results

The inability of the univariate tests to reject non-stationarity and market efficiency could be due to their extremely low test power. This provides motivation for the application of quantile unit root testing outlined in Section 3. As Koenker and Xiao (2014) pointed out, there are potential power gains in quantile unit root testing over the ADF test when the shocks exhibit heavy-tailed behavior. Estimation results for quantile unit root testing are reported in Table 3. We conduct the tests for the case of a trend and no trend. However, we present only the results for the case of no trend because the deterministic time trend estimates are not statistically significant in most of the cases.

First, we analyze the QKS test to provide an overall view of real stock prices over the range of quantiles. The QKS test rejects the unit root null hypothesis at the 5% significance

level or better in most of the cases except for Australia¹ and the Philippines. Overall, these results support mean reversion in real stock prices after taking into account the lower and upper quantiles. This global mean reversion finding is highly relevant for investors since it implies that they will have the opportunity to predict future movements in stock prices based on historical behavior in order to earn excess returns. If stock prices are mean reverting in the long run, for instance, then lower returns are followed by higher expected future returns, which could induce investment in equities after a decline in the share market.

INSERT TABLE 3 HERE

Next, we examine the real stock price behavior in each quantile. Overall, the results from Table 3 indicate that the estimates for $\rho_0(\tau)$ and $\rho_1(\tau)$ are varied across quantiles. Note that $\rho_0(\tau)$ reflects the size of the observed shock on real stock price in the τ th quantile. A negative (positive) sign captures a negative (positive) shock which can be attributed to economic recession (boom). The higher the values of $\rho_0(\tau)$, the larger the values of τ for all countries. Furthermore, the magnitude of the shock at the lower quantiles is not significantly different from zero at the 5% level for most of the countries except for China, Indonesia, Malaysia, South Korea and Thailand. The sizes of shocks, however, vary across countries. Malaysia (Australia) has the most (least) dispersive shocks, ranging from -0.391 to 0.723 (0.006 to 0.189).

The prime coefficient of interest in Table 3 is the estimated value of $\rho_1(\tau)$ and its corresponding unit root test. The results generally indicate that shocks to real stock prices are short-lived in certain quantiles, while the prices contain a unit root wherein the shocks to real prices are more permanent in other quantiles. Specifically, estimates for $\rho_1(\tau)$ at the 70% to

¹ The global non-stationarity of real stock prices for Australia is consistent with the efficient market hypothesis and corroborates with Narayan (2005) who employed the unit root test proposed by Caner and Hansen (2001).

90% quantiles are negative and significant throughout, thereby rejecting the unit-root null for all countries, and implies mean-reversion. Also, the estimates for $\rho_1(\tau)$ at the 60% quantile are significantly different from zero for Indonesia, Japan, Malaysia, Singapore, Thailand, Taiwan. Therefore, the behavior of real stock prices in all countries exhibits mean reversion in high quantiles. This means that positive shocks tend to have transitory effects in real stock prices. In contrast, based on the insignificance of $\rho_1(\tau)$, non-stationarity tends to prevail in low quantiles (50% and below) in most of the countries. This means that negative shocks tend to have permanent effects on real stock prices.

Figure 2 illustrates the above estimates for $\rho_0(\tau)$ and $\rho_1(\tau)$ along with their 95% confidence intervals obtained from the bootstrapping procedure. The estimates for $\rho_0(\tau)$ in most cases tend to increase, passing through the zero point at least at the 60% quantile or higher. Additionally, the estimates for $\rho_0(\tau)$ are higher for Malaysia and Taiwan, which can be attributed to large exogenous shocks (such as financial crises or critical economic events) to stock prices of these two countries. These shocks might push the estimate of $\rho_0(\tau)$ up or down. As for the autoregressive coefficient $\rho_1(\tau)$, we find that their values decrease with τ in the cases of China, Indonesia, Japan, Malaysia, South Korea and Thailand. Indeed, the values of $\rho_1(\tau)$ in these countries are more negative in the high quantiles. By contrast, Australia, Hong Kong, New Zealand, Philippines, Singapore and Taiwan are characterized by $\rho_1(\tau)$, which seems to have no significant variation across the quantiles. In the cases of Australia and the Philippines, they mostly exhibit a zero slope inside the confidence interval thereby lending visual support for these two countries being non-stationary in majority of the quantiles. In addition, combining the results of $\rho_0(\tau)$ and $\rho_1(\tau)$ shows that in the presence of positive shocks, real stock prices would revert to its long-run equilibrium level, but extreme negative shocks seem to lack the ability to induce mean reversion. This finding is consistent with Shen and Holmes (2014) who

found that real stock prices of Asia-Pacific countries are characterized by two stationary regimes with different speeds of adjustment based on Markov regime-switching approach.

INSERT FIGURE 2 HERE

Table 3 also reports the results of HLs associated with the quantiles where real stock prices are stationary. For each country, the stationary cases of $\rho_1(\tau)$ are characterized by very different dynamic properties. To be specific, there are marked differences in the estimated HLs in the stationary cases of $\rho_1(\tau)$, especially in the highest quantile (90%). Malaysia and Thailand are characterized by a much faster speed of adjustment with HLs of 4 to 5 months, compared with a relatively comparable speed of adjustment with HLs of 4 to 11 months for Hong Kong, Indonesia, Singapore, South Korea and Thailand. These short HLs indicate that real stock prices can quickly return to the long-run level when the stock prices are hit by a large positive shock. Meanwhile, New Zealand, China and Japan have a relatively slow speed of adjustment with HLs of 12 to 13 months. In contrast, Australia and the Philippines are characterized by a much slower speed of adjustment with HLs of 21 to 22 months. However, in the extreme low quantile (10%), the estimated HLs are infinite in most of the cases, meaning that stock prices have no tendency to revert to its long-run equilibrium level.

The above results indicate that that the dynamic behavior of real stock prices in our sample countries is asymmetric. That is, real stock prices are far from persistent and therefore mean-reverting in the upper quantiles, but contain a unit root and therefore non-stationary in the lower quantiles. According to Shen and Holmes (2014), such asymmetry can be due to the existence of market frictions and transaction costs. If bid-ask spreads, short-selling and borrowing constraints are present, small deviations from the equilibrium are expected to be unprofitable for investors. Meanwhile, only the presence of large and profitable deviations from the equilibrium would induce ensuing revision to the equilibrium. Consequently, the dynamic

behavior of equity returns will vary depending on the size of the deviation from equilibrium, and hence leads to asymmetric behavior of the equity returns (Dumas, 1992; He and Modest, 1995; Shleifer, 2000).

From a policy perspective, our empirical results suggest that real stock prices do not follow a mean reverting process when a large negative shock such as financial crisis hits stock prices. In this situation, stock market inefficiency may occur so that the authorities may need to intervene through equity market invention policies in order to help investors in forecasting future movements in stock prices more accurately. On the contrary, real stock prices are mean reverting when a positive shock such as economic boom hits the stock market. It means that future movements in stock prices can be predicted based on past stock prices. This suggests that institutional and regulatory mechanisms will not be so important, compared with the situation where historical stock price movements could be used in order to earn excess returns.

4.3 Quantile regression results before and after the global financial crisis

We first consider whether our findings in Table 3 remain robust before the global financial crisis. Since economies around the world have experienced financial market turmoil, this may have impacted on the analysis. To this end, we divide our sample into two subsample periods from 1987:M1–2007:M12 and 2010:M1–2018:M8 for the before and after the global financial crisis periods, respectively.

Table 4 presents new estimation results based on the two subsample periods. In comparison with the results in Table 3, the counterparts in Table 4 show the following observations. First, the QKS still indicates that real stock prices are globally mean-reverting but only for China, Malaysia, New Zealand, South Korea and Taiwan. In addition, the QKS test still fails to reject the unit root null for Australia and the Philippines. In contrast to the preceding

results, the QKS test exhibits low power performance and cannot reject the unit root null in real stock prices for Hong Kong, Indonesia, Japan, Singapore and Taiwan.

Table 4 also shows that although the values of $\rho_0(\tau)$ are slightly different from those in Table 3, they similarly increase as the quantiles get large. Finally, except for Australia, Philippines, Singapore and Thailand, the persistence of real stock prices is still asymmetric depending on the signs and sizes of the shocks. The estimates for $\rho_1(\tau)$ are not significantly different from zero across all quantiles for Australia or for most of the quantiles in the cases of the Philippines, Singapore and Thailand. This suggests that real stock prices follow a unit root process in the subsample period before the global financial crisis. Furthermore, the estimated HLs increase in most of the countries before the global financial crisis, while Japan, New Zealand and South Korea are characterized by a much slower speed of adjustment. For example, in New Zealand the estimated HLs noticeably decrease to 13.33, 9.95 and 8.06 from 33.86, 23.93 and 12.05 for 70%, 80% and 90% quantiles, respectively.

Next, we consider whether the behavior of real stock prices changed after the global financial crisis and report the results in Table 5. With the exception of Japan and New Zealand, the QKS test still indicates that real stock prices are globally mean-reverting in most countries including Australia and the Philippines which were previously globally non-stationary in Table 3. This finding implies that stock prices follow a stationary process and more so after the global financial crisis. Also, the estimates for $\rho_0(\tau)$ differ slightly from those in Table 3 but they still indicate that the impact of positive shocks on stock prices is larger than negative shocks even after the global financial crisis. Furthermore, there is still asymmetry in the persistence of stock prices in most countries but its degree generally increased in most quantiles. Indeed, the estimated values of $\rho_1(\tau)$ are now significantly different from zero in most quantiles for majority of the cases.

In view of HLLs, the findings of asymmetry in the speed of real stock price adjustment across different quantiles remains for most countries, except for New Zealand. In contrast to the preceding results, however, Table 5 shows that most of the countries are characterized by a much faster speed of adjustment in the stationary cases of $\rho_1(\tau)$ after the global financial crisis. One plausible reason for this faster speed of mean reversion is the strong response from arbitrage and investment opportunities and activities that originated from a large disequilibrium in the stock market during the global financial crisis. Investors may have overreacted not only to local news, but also to news originating in the other markets even in the aftermath of the shock of global financial crisis. The significant disequilibrium in these equity markets would not be expected to attract a strong response from international speculators.

Finally, we take into account a possible structural break that could have resulted from the 2008-2009 global financial crisis. Neglecting structural breaks could lead to spuriously high estimates of the degree of persistence. To this end, we capture the possible mean shift by following Tsong and Lee (2011) by re-writing Δs_t in Eq. (1) as follows:

$$\Delta z_t = \rho_0 + \rho_1 z_{t-1} + \sum_{i=1}^q \gamma_i \Delta z_{t-i} + \varepsilon_t \quad (7)$$

where $z_t = \pi_t - \hat{\mu}_0 - \hat{\mu}_1 D_t$. Here $\hat{\mu}_0$ and $\hat{\mu}_1$ are ordinary least square (OLS) estimates of μ_0 and μ_1 , respectively, obtained from the regression of s_t on $(1, D_t)'$ and D_t is an indicator function taking unity if $t \geq s_t$, and zero otherwise, with s_t being a known start date of the global financial crisis. On the basis of the new calculation of π_t in Eq.(7), Table 6 presents re-estimated QKS test results, $\rho_0(\tau)$ and $\rho_1(\tau)$ coefficients, and HLLs obtained using the same methodology as described Section 2.

INSERT TABLE 6 HERE

As shown in Table 6, the main findings in Table 3 remain unchanged. The results are summarized as follows. First, the QKS test still indicates that real stock prices are globally mean-reverting in most of the cases except for Australia and the Philippines. Second, the estimates for $\rho_0(\tau)$ still increase with quantiles. Finally, the persistence of real stock prices is still asymmetric depending on the signs and sizes of the shocks. In particular, the stationarity (non-stationarity) of real stock prices tends to prevail in high (low) quantiles.

5. Conclusion

In this paper, we examined the dynamic behavior of real stock prices and the impact of the GFC on share market efficiency. In contrast with Shen and Holmes (2014a), who used a Markov regime-switching unit root testing, and Anagnostidis et al. (2016), who applied the Generalized Hurst Exponent method, we employed the quantile unit root testing developed by Koenker and Xiao (2004), which accounts for possible asymmetric speed of adjustment of stock prices toward to its long-run equilibrium level.

The quantile unit root testing results suggest stationarity in real stock prices at the upper quantiles only, which are characterized by a varied speed of adjustment. The results further suggest that there are asymmetries in the dynamic adjustments of real stock prices, which indicates that large positive shocks tend to induce strong mean reversion but the same does not hold for large negative shocks. Thus, any equity market intervention policies designed to influence the behavior of the real stock prices without taking account of the signs and sizes of shocks affecting the stock markets is likely to be ineffective. We also find that real stock prices in most of our sample of 12 Asia-Pacific countries exhibit more significant mean-reverting patterns with a faster speed of adjustment after the GFC, signaling increased investment in equities after a market downturn.

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Table 1. Summary statistics for monthly real stock prices

Country	Mean	S.D.	Skewness	Kurtosis	JB stat. (<i>p</i> -value)
Australia	94.552	21.329	0.366	3.262	8.365** (0.015)
China	74.084	41.755	0.587	3.193	19.568*** (0.000)
Hong Kong	94.289	26.935	0.075	2.162	10.034*** (0.007)
Indonesia	85.669	35.874	-0.359	1.795	27.215*** (0.000)
Japan	93.889	23.733	-0.270	2.022	17.277*** (0.000)
Malaysia	91.260	19.221	0.299	3.569	9.448*** (0.009)
New Zealand	134.978	24.315	0.000	2.122	10.676*** (0.005)
Philippines	139.828	60.362	0.792	3.107	34.842*** (0.000)
Singapore	144.125	32.567	-0.167	2.065	13.636*** (0.001)
South Korea	78.626	31.772	0.169	1.786	21.975*** (0.000)
Taiwan	113.331	22.666	0.446	3.527	14.844*** (0.001)
Thailand	135.698	67.150	1.016	3.887	67.959*** (0.000)

Notes: JB stat. denotes the Jarque–Bera normality test, which is $\chi^2(2)$ distributed asymptotically.

Table 2. Results for univariate unit root tests on monthly real stock prices

Country	ADF		DF-GLS		PP		NP		KPSS	
	No trend	With trend	No trend	With trend	No trend	With trend	No trend	With trend	No trend	With trend
Australia	-2.188	-2.533	-0.154	-1.973	-2.255	-2.704	-0.218	-2.105	1.316 ^{***}	0.225 ^{***}
China	-2.713 [*]	-4.551 ^{***}	-1.074	-4.397 ^{***}	-2.384	-3.788 ^{**}	-0.895	-3.629 ^{***}	1.650 ^{***}	0.068
Hong Kong	-2.395	-3.711 ^{**}	-0.464	-3.246 ^{**}	-2.473	-3.805 ^{**}	-0.510	-3.223 ^{**}	1.659 ^{***}	0.086
Indonesia	-1.939	-2.549	-1.050	-1.207	-2.121	-2.754	-1.147	-1.279	0.748 ^{***}	0.409 ^{***}
Japan	-2.564	-2.864	-1.579	-2.828 [*]	-2.229	-2.412	-1.324	-2.335	0.686 ^{**}	0.199 ^{**}
Malaysia	-3.488 ^{***}	-3.776 ^{**}	-1.770 [*]	-3.402 ^{**}	-3.221 ^{**}	-3.394 [*]	-1.559	-2.963 ^{**}	0.585 ^{**}	0.078
New Zealand	-2.320	-2.336	-0.445	-1.719	-2.273	-2.275	-0.329	-1.621	0.204	0.139 [*]
Philippines	-1.658	-1.687	-1.080	-1.469	-1.946	-2.030	-1.213	-1.593	0.418 [*]	0.332 ^{***}
Singapore	-2.862 [*]	-2.643	-1.667 [*]	-2.240	-2.573 [*]	-2.405	-1.616 [*]	-2.111	0.365 [*]	0.150 ^{**}
South Korea	-1.302	-3.320 [*]	-0.797	-2.522	-1.091	-3.236 [*]	-0.602	-2.367	1.841 ^{***}	0.212 ^{**}
Taiwan	-3.735 ^{***}	-3.792 ^{**}	-2.299 ^{**}	-3.606 ^{***}	-3.582 ^{***}	-3.630 ^{**}	-2.434 ^{**}	-3.339 ^{**}	0.141	0.124 [*]
Thailand	-1.775	-1.666	-1.778 [*]	-1.777	-1.589	-1.542	-0.895	-3.629 ^{***}	1.650 ^{***}	0.068

Notes: The optimal lag length for ADF is determined using Schwarz Info Criterion (1978). We select bandwidth by the Barlett Kernel, as suggested by the Newey and West (1987) test for PP and NP. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

Table 3. Quantile ADF unit root results for the whole sample period, January 1991-August 2018

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Australia	$\rho_0(\tau)$	0.078	0.006	0.116**	0.066	0.085*	0.100**	0.093*	0.164***	0.189***
	p -value	0.282	0.916	0.017	0.132	0.053	0.032	0.067	0.004	0.005
	$\rho_1(\tau)$	-0.028*	-0.009	-0.029**	-0.015	-0.017	-0.018	-0.015	-0.028**	-0.031**
	p -value	0.072	0.325	0.047	0.448	0.272	0.102	0.118	0.017	0.021
	Half-lives	24.099	∞	23.362	∞	∞	∞	∞	∞	24.216
	QKS/ p -value	2.745(0.128)								
China	$\rho_0(\tau)$	-0.144***	-0.108**	-0.059	0.014	0.047	0.082**	0.179***	0.292***	0.341***
	p -value	0.008	0.016	0.144	0.712	0.212	0.032	0.000	0.000	0.000
	$\rho_1(\tau)$	0.008	0.011	0.006	-0.006	-0.009	-0.013	-0.031***	-0.052***	-0.052***
	p -value	0.665	0.844	0.797	0.459	0.434	0.163	0.002	0.000	0.000
	Half-lives	∞	∞	∞	∞	∞	∞	∞	21.904	12.971
	QKS/ p -value	3.740(0.024)**								
Hong Kong	$\rho_0(\tau)$	0.067	-0.070	-0.024	0.001	0.041	0.129**	0.267***	0.364***	0.486***
	p -value	0.444	0.339	0.706	0.990	0.497	0.034	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.032	0.005	0.000	-0.002	-0.008	-0.025	-0.051***	-0.068***	-0.090***
	p -value	0.163	0.654	0.596	0.624	0.584	0.118	0.003	0.000	0.000
	Half-lives	∞	∞	∞	∞	∞	∞	∞	13.257	9.829
	QKS/ p -value	4.582(0.012)**								
Indonesia	$\rho_0(\tau)$	-0.148**	-0.101**	-0.069	-0.053	0.029	0.146***	0.237***	0.244***	0.401***
	p -value	0.016	0.041	0.125	0.222	0.491	0.001	0.000	0.000	0.000
	$\rho_1(\tau)$	0.012	0.011	0.009	0.008	-0.005	-0.028**	-0.045***	-0.042***	-0.069***
	p -value	0.733	0.770	0.862	0.878	0.609	0.019	0.000	0.000	0.000
	Half-lives	∞	∞	∞	∞	∞	∞	24.279	15.218	15.995
	QKS/ p -value	4.707(0.013)**								

Notes: All the p -values are calculated with the bootstrap method with 5000 replications. For $\hat{\rho}_0(\tau)$ the null of zero is tested with the student- t test, while for $\hat{\rho}_1(\tau)$, the unit-root null is tested with the $t_n(\tau)$ statistic. ***, ** and * denote significance at the 1, 5 and 10% levels.

Table 3. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Japan	$\rho_0(\tau)$	-0.054	0.079	0.100	0.145**	0.158**	0.131**	0.215***	0.298***	0.323***
	p -value	0.593	0.303	0.136	0.020	0.010	0.039	0.002	0.000	0.001
	$\rho_1(\tau)$	-0.003	-0.024	-0.025*	-0.032**	-0.032*	-0.024*	-0.038***	-0.051***	-0.052***
	p -value	0.445	0.157	0.079	0.049	0.092	0.077	0.009	0.002	0.001
	Half-lives	∞	∞	27.088	21.468	21.572	29.053	17.816	13.195	13.019
	QKS/ p -value	3.162(0.031)**								
Malaysia	$\rho_0(\tau)$	-0.391***	-0.067	-0.113*	0.046	0.155**	0.212***	0.325***	0.451***	0.723***
	p -value	0.000	0.358	0.094	0.466	0.014	0.001	0.000	0.000	0.000
	$\rho_1(\tau)$	0.071	0.006	0.020	-0.012	-0.033*	-0.044**	-0.066***	-0.090***	-0.144***
	p -value	0.994	0.675	0.966	0.347	0.087	0.019	0.002	0.000	0.000
	Half-lives	∞	∞	∞	∞	20.506	15.553	10.190	7.342	4.444
	QKS/ p -value	6.913(0.000)***								
New Zealand	$\rho_0(\tau)$	0.043	0.028	0.093	0.156***	0.151**	0.109*	0.120*	0.168**	0.318***
	p -value	0.641	0.698	0.140	0.008	0.010	0.072	0.063	0.017	0.000
	$\rho_1(\tau)$	-0.018	-0.011	-0.022	-0.033*	-0.030	-0.020	-0.020**	-0.029**	-0.056***
	p -value	0.296	0.349	0.165	0.061	0.119	0.105	0.046	0.016	0.008
	Half-lives	∞	∞	∞	20.917	∞	∞	33.860	23.927	12.051
	QKS/ p -value	3.175(0.085)*								
Philippines	$\rho_0(\tau)$	-0.029	-0.001	0.022	0.026	0.041	0.066	0.121**	0.202***	0.237***
	p -value	0.689	0.988	0.657	0.573	0.372	0.164	0.018	0.000	0.001
	$\rho_1(\tau)$	-0.012	-0.011	-0.011	-0.008	-0.007	-0.010	-0.017*	-0.030**	-0.032**
	p -value	0.300	0.290	0.293	0.478	0.664	0.350	0.087	0.011	0.029
	Half-lives	∞	∞	∞	∞	∞	∞	40.244	22.718	21.505
	QKS/ p -value	2.571(0.140)								

Notes: All the p -values are calculated with the bootstrap method with 5000 replications. For $\hat{\rho}_0(\tau)$ the null of zero is tested with the student- t test, while for $\hat{\rho}_1(\tau)$, the unit-root null is tested with the $t_n(\tau)$ statistic. ***, ** and * denote significance at the 1, 5 and 10% levels.

Table 3. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Singapore	$\rho_0(\tau)$	0.187*	0.048	0.021	0.082	0.164**	0.205***	0.249***	0.313***	0.458***
	p -value	0.064	0.568	0.776	0.242	0.019	0.004	0.001	0.000	0.000
	$\rho_1(\tau)$	-0.056*	-0.019	-0.009	-0.020	-0.035*	-0.042**	-0.049***	-0.060***	-0.088***
	p -value	0.059	0.262	0.417	0.279	0.079	0.024	0.006	0.002	0.001
	Half-lives	12.100	∞	∞	∞	19.210	16.170	13.724	11.129	7.546
	QKS/ p -value	3.935(0.027)**								
South Korea	$\rho_0(\tau)$	-0.306***	-0.200***	-0.172***	-0.090**	-0.027	0.089**	0.193***	0.293***	0.546***
	p -value	0.000	0.000	0.000	0.043	0.528	0.042	0.000	0.000	0.000
	$\rho_1(\tau)$	0.052	0.034	0.032	0.017	0.007	-0.016	-0.036***	-0.055***	-0.106***
	p -value	0.998	0.997	1.000	0.984	0.981	0.127	0.002	0.000	0.000
	Half-lives	∞	∞	∞	∞	∞	∞	18.983	12.308	6.214
	QKS/ p -value	6.611(0.001)***								
Taiwan	$\rho_0(\tau)$	0.194	0.128	0.049	0.288***	0.241**	0.327***	0.438***	0.523***	0.698***
	p -value	0.224	0.296	0.647	0.004	0.014	0.001	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.061	-0.039	-0.017	-0.064**	-0.051	-0.065**	-0.086***	-0.099***	-0.130***
	p -value	0.105	0.175	0.354	0.026	0.172	0.017	0.002	0.001	0.001
	Half-lives	∞	∞	∞	10.517	∞	10.309	7.732	6.640	4.964
	QKS/ p -value	4.208(0.016)**								
Thailand	$\rho_0(\tau)$	-0.230***	-0.079	-0.015	0.001	0.103**	0.140***	0.208***	0.295***	0.393***
	p -value	0.002	0.182	0.778	0.985	0.042	0.007	0.000	0.000	0.000
	$\rho_1(\tau)$	0.027	0.004	-0.004	-0.003	-0.020	-0.025**	-0.036***	-0.049***	-0.064***
	p -value	0.815	0.652	0.469	0.638	0.162	0.041	0.002	0.000	0.000
	Half-lives	∞	∞	∞	∞	∞	27.735	19.096	13.755	10.536
	QKS/ p -value	3.836(0.027)**								

Notes: All the p -values are calculated with the bootstrap method with 5000 replications. For $\hat{\rho}_0(\tau)$ the null of zero is tested with the student- t test, while for $\hat{\rho}_1(\tau)$, the unit-root null is tested with the $t_n(\tau)$ statistic. ***, ** and * denote significance at the 1, 5 and 10% levels.

Table 4. Quantile ADF unit root results for the pre-Global Financial Crisis period

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Australia	$\rho_0(\tau)$	0.010	-0.011	-0.027	-0.013	0.039	0.014	-0.006	0.086	0.138*
	p -value	0.906	0.864	0.610	0.784	0.417	0.785	0.912	0.161	0.068
	$\rho_1(\tau)$	-0.012	-0.004	0.004	0.003	-0.006	0.002	0.008	-0.011	-0.019
	p -value	0.250	0.443	0.715	0.840	0.646	0.716	0.866	0.255	0.115
	Half-lives	∞	∞	∞	∞	∞	∞	∞	∞	∞
	QKS/ p -value	1.154(0.527)								
China	$\rho_0(\tau)$	-0.225***	-0.113*	-0.028	0.016	0.050	0.074	0.144***	0.297***	0.301***
	p -value	0.003	0.067	0.623	0.767	0.334	0.150	0.007	0.000	0.000
	$\rho_1(\tau)$	0.029	0.012	-0.004	-0.008	-0.011	-0.012	-0.023*	-0.053***	-0.042**
	p -value	0.941	0.826	0.497	0.538	0.642	0.450	0.092	0.001	0.035
	Half-lives	∞	∞	∞	∞	∞	∞	29.547	12.641	16.296
	QKS/ p -value	3.394(0.033)**								
Hong Kong	$\rho_0(\tau)$	0.161	0.142	0.059	-0.008	0.026	0.101	0.220**	0.277**	0.479***
	p -value	0.253	0.214	0.569	0.937	0.783	0.286	0.034	0.018	0.001
	$\rho_1(\tau)$	-0.056	-0.044***	-0.020	0.000	-0.004	-0.019	-0.041	-0.049*	-0.089***
	p -value	0.107	0.097	0.312	0.688	0.790	0.439	0.111	0.058	0.008
	Half-lives	∞	15.533	∞	∞	∞	∞	∞	13.783	7.429
	QKS/ p -value	2.753(0.123)								
Indonesia	$\rho_0(\tau)$	-0.099	-0.022	-0.039	-0.015	0.061	0.087	0.206***	0.209***	0.274***
	p -value	0.246	0.753	0.531	0.796	0.510	0.144	0.001	0.003	0.002
	$\rho_1(\tau)$	-0.003	-0.011	0.000	-0.001	-0.014	-0.016	-0.039**	-0.034**	-0.039**
	p -value	0.430	0.308	0.628	0.631	0.298	0.346	0.015	0.025	0.042
	Half-lives	∞	∞	∞	∞	∞	∞	17.628	20.024	17.424
	QKS/ p -value	2.482(0.138)								

Notes: See the notes for Table 3.

Table 4. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
Japan	$\rho_0(\tau)$	0.082	0.115	0.111	0.128	0.142	0.173*	0.261**	0.281**	0.367**	
	p -value	0.589	0.331	0.289	0.180	0.126	0.071	0.011	0.015	0.015	
	$\rho_1(\tau)$	-0.030	-0.031	-0.027	-0.028	-0.028	-0.032	-0.047**	-0.048**	-0.060**	
	p -value	0.164	0.182	0.194	0.220	0.358	0.120	0.030	0.023	0.015	
	Half-lives	∞	∞	∞	∞	∞	∞	∞	14.265	13.943	11.132
	QKS/ p -value	2.349(0.104)									
Malaysia	$\rho_0(\tau)$	-0.229	0.072	0.070	0.190*	0.243**	0.239**	0.272***	0.389***	0.687***	
	p -value	0.112	0.514	0.490	0.051	0.011	0.014	0.009	0.001	0.000	
	$\rho_1(\tau)$	0.032	-0.027	-0.023	-0.046*	-0.054	-0.050*	-0.053**	-0.076**	-0.135***	
	p -value	0.775	0.204	0.215	0.091	0.102	0.060	0.025	0.010	0.001	
	Half-lives	∞	∞	∞	14.596	∞	13.454	12.611	8.808	4.766	
	QKS/ p -value	4.144(0.006)***									
New Zealand	$\rho_0(\tau)$	0.006	0.111	0.122	0.300***	0.389***	0.243**	0.274**	0.364***	0.460***	
	p -value	0.966	0.366	0.238	0.002	0.000	0.013	0.010	0.002	0.002	
	$\rho_1(\tau)$	-0.011	-0.029	-0.028	-0.062**	-0.078***	-0.046**	-0.051***	-0.067***	-0.082***	
	p -value	0.357	0.228	0.250	0.026	0.004	0.047	0.008	0.003	0.006	
	Half-lives	∞	∞	∞	10.871	8.511	14.577	13.330	9.954	8.060	
	QKS/ p -value	4.073(0.015)**									
Philippines	$\rho_0(\tau)$	0.112	-0.021	-0.009	0.061	0.036	0.038	0.097	0.165**	0.199**	
	p -value	0.218	0.778	0.893	0.298	0.780	0.516	0.126	0.022	0.028	
	$\rho_1(\tau)$	-0.044	-0.009	-0.007	-0.016	-0.007	-0.004	-0.011	-0.021	-0.020	
	p -value	0.008	0.313	0.410	0.309	0.780	0.677	0.339	0.133	0.141	
	Half-lives	15.461	∞	∞	∞	∞	∞	∞	∞	∞	
	QKS/ p -value	2.345(0.126)									

Notes: See the notes for Table 3.

Table 4. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Singapore	$\rho_0(\tau)$	0.102	0.039	0.051	0.081	0.118	0.203**	0.123	0.211**	0.284**
	p -value	0.397	0.700	0.565	0.347	0.161	0.020	0.175	0.040	0.023
	$\rho_1(\tau)$	-0.037	-0.018	-0.016	-0.020	-0.026	-0.042*	-0.021	-0.037	-0.048
	p -value	0.202	0.319	0.355	0.406	0.417	0.097	0.280	0.130	0.128
	Half-lives	∞	∞	∞	∞	∞	16.352	∞	∞	∞
	QKS/ p -value	2.134(0.262)								
South Korea	$\rho_0(\tau)$	-0.438***	-0.242**	-0.145*	-0.098	-0.016	0.094	0.225***	0.328***	0.583***
	p -value	0.000	0.013	0.095	0.220	0.834	0.224	0.008	0.001	0.000
	$\rho_1(\tau)$	0.085	0.045	0.025	0.019	0.004	-0.018	-0.044*	-0.064**	-0.115***
	p -value	0.999	0.983	0.951	0.962	0.942	0.414	0.060	0.012	0.000
	Half-lives	∞	∞	∞	∞	∞	∞	15.257	10.469	5.649
	QKS/ p -value	3.704(0.030)**								
Taiwan	$\rho_0(\tau)$	0.230	0.179	0.202	0.255*	0.306**	0.295**	0.333**	0.595***	0.633***
	p -value	0.276	0.281	0.166	0.057	0.019	0.026	0.022	0.000	0.003
	$\rho_1(\tau)$	-0.071*	-0.052*	-0.051	-0.058*	-0.066	-0.059	-0.061	-0.112**	-0.112**
	p -value	0.054	0.094	0.102	0.094	0.200	0.255	0.143	0.013	0.036
	Half-lives	9.387	12.979	∞	11.594	∞	∞	∞	5.863	5.861
	QKS/ p -value	3.158(0.060)*								
Thailand	$\rho_0(\tau)$	-0.233**	0.018	0.010	0.034	0.057	0.095	0.183***	0.265***	0.240***
	p -value	0.015	0.807	0.877	0.591	0.357	0.132	0.006	0.000	0.008
	$\rho_1(\tau)$	0.022	-0.019	-0.010	-0.012	-0.013	-0.017	-0.030*	-0.042**	-0.027
	p -value	0.727	0.231	0.338	0.351	0.549	0.336	0.052	0.012	0.192
	Half-lives	∞	∞	∞	∞	∞	∞	22.651	16.107	∞
	QKS/ p -value	2.735(0.157)								

Notes: See the notes for Table 3.

Table 5. Quantile ADF unit root results for the post-Global Financial Crisis period

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Australia	$\rho_0(\tau)$	0.086	0.455*	0.548**	0.660***	0.566***	0.470**	0.777***	0.868***	0.961***
	p -value	0.785	0.074	0.010	0.001	0.004	0.023	0.001	0.001	0.001
	$\rho_1(\tau)$	-0.028	-0.104*	-0.121**	-0.142**	-0.120*	-0.098**	-0.162***	-0.179***	-0.198***
	p -value	0.358	0.052	0.028	0.010	0.062	0.022	0.000	0.003	0.001
	Half-lives	∞	6.296	5.374	4.511	5.422	6.734	3.929	3.515	3.148
	QKS/ p -value	3.418(0.035)**								
China	$\rho_0(\tau)$	0.737***	0.656***	0.196	0.278	0.229	0.133	0.170	0.244	0.090
	p -value	0.006	0.003	0.269	0.107	0.177	0.446	0.355	0.228	0.739
	$\rho_1(\tau)$	-0.176***	-0.153***	-0.047	-0.062	-0.048	-0.024	-0.029	-0.042	0.000
	p -value	0.006	0.008	0.364	0.313	0.383	0.405	0.335	0.237	0.549
	Half-lives	3.587	4.178	∞	∞	∞	∞	∞	∞	∞
	QKS/ p -value	3.271(0.030)**								
Hong Kong	$\rho_0(\tau)$	-0.079	-0.039	0.584***	0.528***	0.494**	0.728***	0.957***	1.137***	1.035***
	p -value	0.786	0.868	0.003	0.006	0.011	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	0.005	0.002	-0.124***	-0.110*	-0.101**	-0.148***	-0.193***	-0.228***	-0.205***
	p -value	0.602	0.633	0.002	0.050	0.047	0.000	0.000	0.001	0.000
	Half-lives	∞	∞	5.240	5.945	6.497	4.332	3.230	2.677	3.029
	QKS/ p -value	4.506(0.004)***								
Indonesia	$\rho_0(\tau)$	0.180	0.174	0.749***	1.001***	1.019***	0.974***	0.961***	0.951***	1.057***
	p -value	0.467	0.337	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.053	-0.044	-0.160***	-0.210***	-0.211***	-0.200***	-0.195***	-0.191***	-0.208***
	p -value	0.260	0.236	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Half-lives	∞	∞	3.983	2.935	2.925	3.109	3.192	3.265	2.965
	QKS/ p -value	7.232(0.000)***								

Notes: See the notes for Table 3.

Table 5. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
Japan	$\rho_0(\tau)$	0.002	-0.075	-0.049	0.057	0.100	0.108	0.094	0.311**	0.337**	
	p -value	0.989	0.498	0.619	0.528	0.268	0.246	0.366	0.012	0.021	
	$\rho_1(\tau)$	-0.014	0.009	0.007	-0.012	-0.019	-0.018	-0.012	-0.054*	-0.056**	
	p -value	0.353	0.680	0.771	0.595	0.523	0.399	0.416	0.052	0.027	
	Half-lives	∞	∞	∞	∞	∞	∞	∞	∞	12.563	12.138
	QKS/ p -value	2.123(0.255)									
Malaysia	$\rho_0(\tau)$	0.285	0.319**	0.257**	0.332***	0.305***	0.410***	0.472***	0.569***	0.813***	
	p -value	0.146	0.018	0.035	0.003	0.007	0.000	0.000	0.000	0.000	
	$\rho_1(\tau)$	-0.068*	-0.071**	-0.056	-0.070*	-0.064*	-0.085***	-0.096***	-0.116***	-0.164***	
	p -value	0.064	0.042	0.113	0.054	0.097	0.004	0.000	0.000	0.000	
	Half-lives	9.791	9.432	∞	9.494	10.560	7.794	6.872	5.643	3.861	
	QKS/ p -value	4.319(0.001)***									
New Zealand	$\rho_0(\tau)$	-0.016	0.069	0.007	0.039	0.064	0.042	0.076	0.081	0.110	
	p -value	0.845	0.301	0.908	0.497	0.263	0.482	0.235	0.242	0.168	
	$\rho_1(\tau)$	-0.002	-0.017	-0.003	-0.008	-0.012	-0.006	-0.012	-0.012	-0.016	
	p -value	0.436	0.255	0.520	0.489	0.518	0.544	0.253	0.237	0.154	
	Half-lives	∞	∞	∞	∞	∞	∞	∞	∞	∞	
	QKS/ p -value	1.228(0.453)									
Philippines	$\rho_0(\tau)$	0.025	0.129	0.150	0.153*	0.257***	0.261***	0.310***	0.327***	0.727**	
	p -value	0.854	0.221	0.110	0.076	0.002	0.003	0.001	0.002	0.000	
	$\rho_1(\tau)$	-0.016	-0.032	-0.034	-0.031	-0.050**	-0.048**	-0.057***	-0.057***	-0.132***	
	p -value	0.440	0.217	0.211	0.223	0.017	0.021	0.002	0.000	0.000	
	Half-lives	∞	∞	∞	∞	13.636	13.946	11.837	11.810	4.906	
	QKS/ p -value	4.440(0.037)**									

Notes: See the notes for Table 3.

Table 5. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Singapore	$\rho_0(\tau)$	-0.453	0.274	0.457**	0.488**	0.513***	0.822***	0.857***	1.011***	0.881***
	<i>p</i> -value	0.183	0.235	0.019	0.011	0.008	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	0.085	-0.066	-0.102*	-0.106*	-0.110**	-0.176***	-0.181***	-0.213***	-0.183***
	<i>p</i> -value	0.852	0.220	0.095	0.050	0.037	0.001	0.000	0.000	0.000
	Half-lives	∞	∞	6.466	6.172	5.930	3.588	3.472	2.894	3.432
	QKS/ <i>p</i> -value	4.370(0.007)***								
South Korea	$\rho_0(\tau)$	0.360	0.487**	0.498***	0.561***	0.593***	0.550***	0.508***	0.711***	0.751***
	<i>p</i> -value	0.147	0.011	0.003	0.001	0.000	0.001	0.006	0.001	0.002
	$\rho_1(\tau)$	-0.085*	-0.107***	-0.107**	-0.120***	-0.125**	-0.113**	-0.102**	-0.143***	-0.149***
	<i>p</i> -value	0.079	0.008	0.023	0.009	0.018	0.014	0.022	0.006	0.003
	Half-lives	7.772	6.103	6.104	5.444	5.177	5.763	6.458	4.496	4.295
	QKS/ <i>p</i> -value	3.806(0.015)**								
Taiwan	$\rho_0(\tau)$	-0.268	-0.017	0.239	0.448***	0.316**	0.463***	0.604***	0.845***	0.934***
	<i>p</i> -value	0.233	0.923	0.114	0.001	0.022	0.002	0.000	0.000	0.000
	$\rho_1(\tau)$	0.047	-0.002	-0.053	-0.094*	-0.065	-0.093**	-0.121***	-0.169***	-0.186***
	<i>p</i> -value	0.796	0.531	0.234	0.082	0.245	0.012	0.000	0.000	0.000
	Half-lives	∞	∞	∞	7.002	∞	7.131	5.378	3.738	3.367
	QKS/ <i>p</i> -value	4.466(0.035)**								
Thailand	$\rho_0(\tau)$	0.232	0.231*	0.407***	0.440***	0.525***	0.601***	0.723***	0.719***	0.771***
	<i>p</i> -value	0.215	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.058	-0.051	-0.083***	-0.087***	-0.103***	-0.116***	-0.138**	-0.136***	-0.142**
	<i>p</i> -value	0.188	0.163	0.002	0.001	0.000	0.000	0.011	0.000	0.013
	Half-lives	∞	∞	8.031	7.587	6.403	5.616	4.671	4.754	4.511
	QKS/ <i>p</i> -value	5.348(0.002)***								

Notes: See the notes for Table 3.

Table 6. Quantile ADF unit root results with structural break

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
Australia	$\rho_0(\tau)$	-0.051***	-0.033***	-0.016***	-0.002	0.009***	0.018***	0.027***	0.037***	0.048***	
	p -value	0.000	0.000	0.000	0.430	0.001	0.000	0.000	0.000	0.000	
	$\rho_1(\tau)$	-0.011	0.000	-0.015	-0.012	-0.009	-0.015	-0.015	-0.031**	-0.036***	
	p -value	0.321	0.503	0.239	0.487	0.429	0.156	0.127	0.015	0.009	
	Half-lives	∞	∞	∞	∞	∞	∞	∞	∞	21.790	18.789
	QKS/ p -value	2.157(0.192)									
China	$\rho_0(\tau)$	-0.115***	-0.066***	-0.036***	-0.011	0.009	0.029***	0.057***	0.080***	0.126***	
	p -value	0.000	0.000	0.000	0.157	0.255	0.000	0.000	0.000	0.000	
	$\rho_1(\tau)$	0.012	0.010	0.006	-0.006	-0.010	-0.019*	-0.039***	-0.055***	-0.052***	
	p -value	0.727	0.833	0.796	0.465	0.402	0.065	0.004	0.000	0.000	
	Half-lives	∞	∞	∞	∞	∞	36.583	17.605	12.350	12.971	
	QKS/ p -value	4.652(0.014)**									
Hong Kong	$\rho_0(\tau)$	-0.084***	-0.046***	-0.024***	-0.009**	0.004	0.018***	0.038***	0.058***	0.089***	
	p -value	0.000	0.000	0.000	0.043	0.284	0.000	0.000	0.000	0.000	
	$\rho_1(\tau)$	-0.013	0.009	0.004	-0.002	-0.009	-0.024	-0.055***	-0.070***	-0.117***	
	p -value	0.346	0.723	0.661	0.619	0.530	0.131	0.005	0.000	0.000	
	Half-lives	∞	∞	∞	∞	∞	∞	12.239	9.482	5.567	
	QKS/ p -value	5.435(0.003)***									
Indonesia	$\rho_0(\tau)$	-0.099***	-0.059***	-0.030***	-0.019***	0.006	0.023***	0.044***	0.059***	0.101***	
	p -value	0.000	0.000	0.000	0.001	0.260	0.000	0.000	0.000	0.000	
	$\rho_1(\tau)$	0.010	0.013	0.009	0.009	-0.005	-0.027**	-0.040***	-0.045***	-0.069***	
	p -value	0.719	0.822	0.865	0.894	0.611	0.023	0.001	0.000	0.000	
	Half-lives	∞	∞	∞	∞	∞	25.379	16.956	15.002	9.679	
	QKS/ p -value	4.732(0.011)**									

Notes: See the notes for Table 3.

Table 6. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Japan	$\rho_0(\tau)$	-0.072***	-0.038***	-0.022***	-0.009**	0.005	0.016***	0.029***	0.044***	0.071***
	p -value	0.000	0.000	0.000	0.020	0.175	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	0.068	0.005	0.020	-0.012	-0.035*	-0.044**	-0.067***	-0.085***	-0.147***
	p -value	0.992	0.645	0.965	0.363	0.068	0.018	0.002	0.000	0.000
	Half-lives	∞	∞	∞	∞	19.190	15.482	10.065	7.796	4.373
	QKS/ p -value	7.053(0.000)***								
Malaysia	$\rho_0(\tau)$	-0.065***	-0.040***	-0.019***	-0.006*	0.005	0.016***	0.027***	0.042***	0.063***
	p -value	0.000	0.000	0.000	0.076	0.167	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.045	-0.014	-0.006	-0.020	-0.036*	-0.047**	-0.042**	-0.063***	-0.084***
	p -value	0.121	0.326	0.458	0.294	0.082	0.014	0.019	0.002	0.006
	Half-lives	∞	∞	∞	∞	19.093	14.377	16.313	10.618	7.880
	QKS/ p -value	3.618(0.041)**								
New Zealand	$\rho_0(\tau)$	-0.045***	-0.027***	-0.013***	-0.003	0.005**	0.014***	0.021***	0.029***	0.045***
	p -value	0.000	0.000	0.000	0.125	0.012	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.024	-0.013	-0.021	-0.024	-0.027	-0.020	-0.020**	-0.028**	-0.056***
	p -value	0.225	0.324	0.185	0.173	0.150	0.105	0.046	0.017	0.008
	Half-lives	∞	∞	∞	∞	∞	∞	33.860	24.031	12.051
	QKS/ p -value	3.178(0.086)*								
Philippines	$\rho_0(\tau)$	-0.089***	-0.053***	-0.032***	-0.014**	0.005	0.020***	0.038***	0.058***	0.085***
	p -value	0.000	0.000	0.000	0.001	0.232	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.011	-0.011	-0.014	-0.010	-0.009	-0.010	-0.017	-0.033***	-0.036**
	p -value	0.312	0.281	0.224	0.415	0.610	0.332	0.106	0.008	0.019
	Half-lives	∞	∞	∞	∞	∞	∞	∞	20.951	18.971
	QKS/ p -value	2.667(0.123)								

Notes: See the notes for Table 3.

Table 6. (Continued)

Country	τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Singapore	$\rho_0(\tau)$	-0.071***	-0.040***	-0.025***	-0.012***	0.002	0.015***	0.026***	0.045***	0.066***
	p -value	0.000	0.000	0.000	0.000	0.547	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.003	-0.024	-0.026*	-0.031*	-0.032*	-0.024*	-0.039***	-0.051***	-0.052***
	p -value	0.448	0.152	0.070	0.052	0.090	0.077	0.008	0.001	0.001
	Half-lives	∞	∞	26.218	21.740	21.572	29.053	17.440	13.319	13.019
	QKS/ p -value	3.148(0.030)**								
South Korea	$\rho_0(\tau)$	-0.088***	-0.056***	-0.035***	-0.018***	0.001	0.021***	0.039***	0.058***	0.096***
	p -value	0.000	0.000	0.000	0.000	0.817	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	0.054	0.038	0.032	0.017	0.006	-0.016	-0.037***	-0.051***	-0.106***
	p -value	0.999	0.999	1.000	0.987	0.971	0.114	0.005	0.000	0.000
	Half-lives	∞	∞	∞	∞	∞	∞	18.522	13.119	6.161
	QKS/ p -value	6.332(0.001)***								
Taiwan	$\rho_0(\tau)$	-0.094***	-0.055***	-0.030***	-0.012***	0.004	0.021***	0.034***	0.055***	0.083***
	p -value	0.000	0.000	0.000	0.003	0.335	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	-0.061	-0.039	-0.018	-0.061**	-0.044	-0.066**	-0.086***	-0.090***	-0.125***
	p -value	0.105	0.185	0.344	0.031	0.262	0.014	0.002	0.002	0.001
	Half-lives	∞	∞	∞	11.025	∞	10.187	7.732	7.376	5.186
	QKS/ p -value	4.074(0.023)**								
Thailand	$\rho_0(\tau)$	-0.104***	-0.059***	-0.035***	-0.013**	0.004	0.021***	0.038***	0.059***	0.094***
	p -value	0.000	0.000	0.000	0.015	0.474	0.000	0.000	0.000	0.000
	$\rho_1(\tau)$	0.028	0.003	-0.004	-0.006	-0.020	-0.027**	-0.035***	-0.049***	-0.051***
	p -value	0.817	0.617	0.472	0.534	0.183	0.029	0.002	0.000	0.006
	Half-lives	∞	∞	∞	∞	∞	25.028	19.193	13.748	13.291
	QKS/ p -value	3.889(0.042)**								

Notes: See the notes for Table 3.

Figure 1. Real stock price indices in 12 Asia-Pacific countries

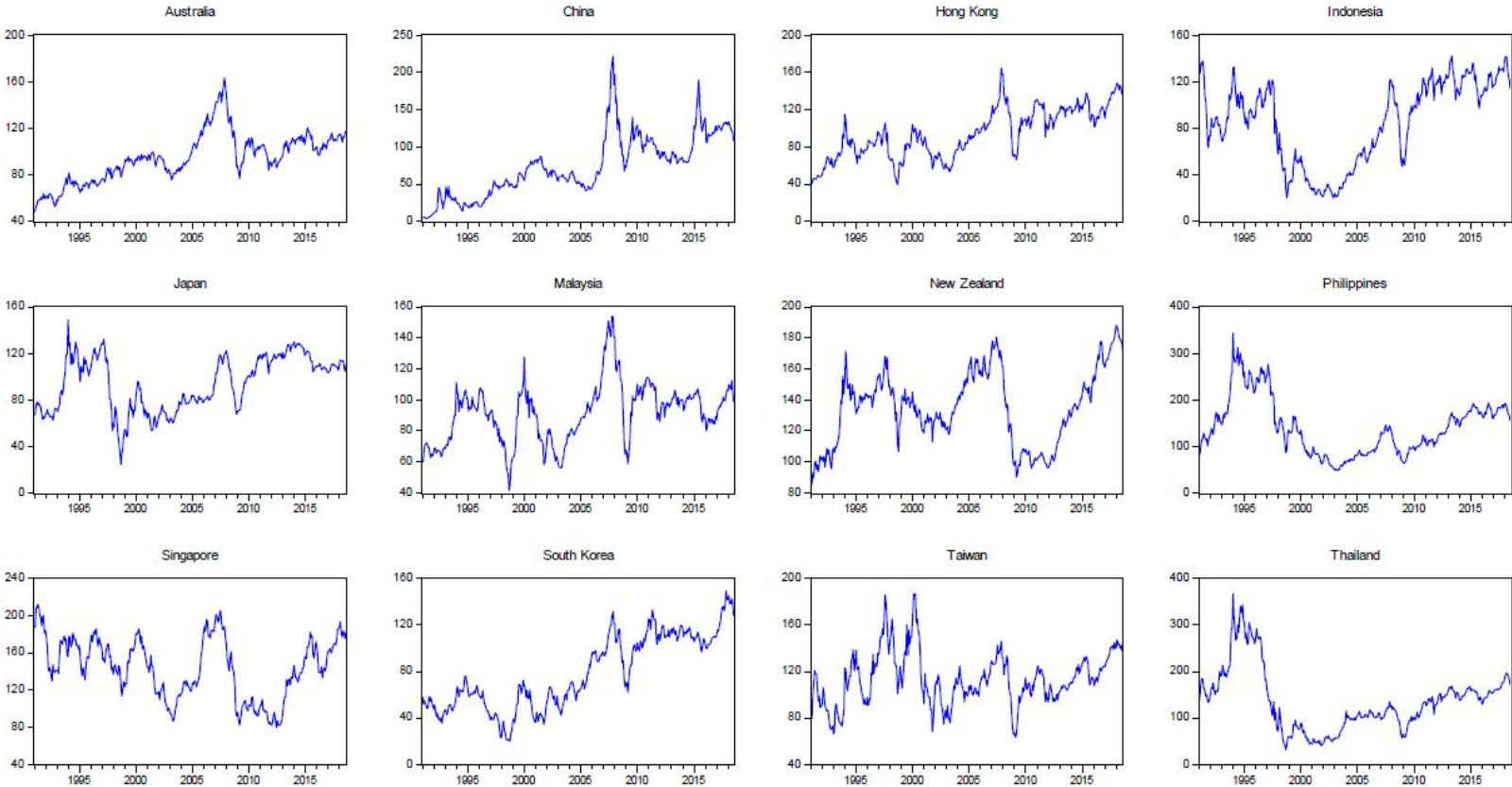


Figure 2. Quantile intercepts (ρ_0), autoregressive coefficients (ρ_1).
 Notes: The dashed lines signify the 95% confidence levels.

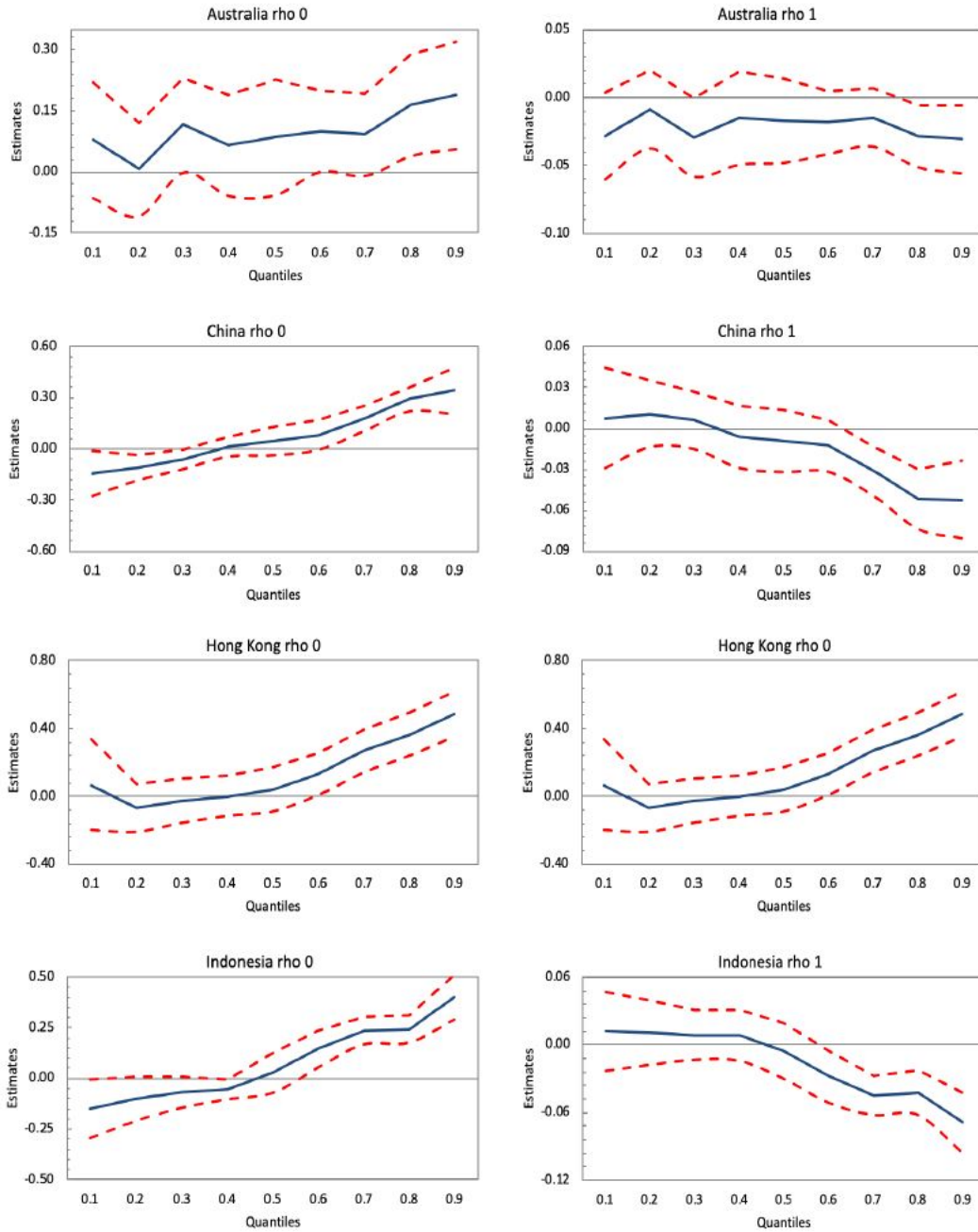


Figure 2. (Continued)

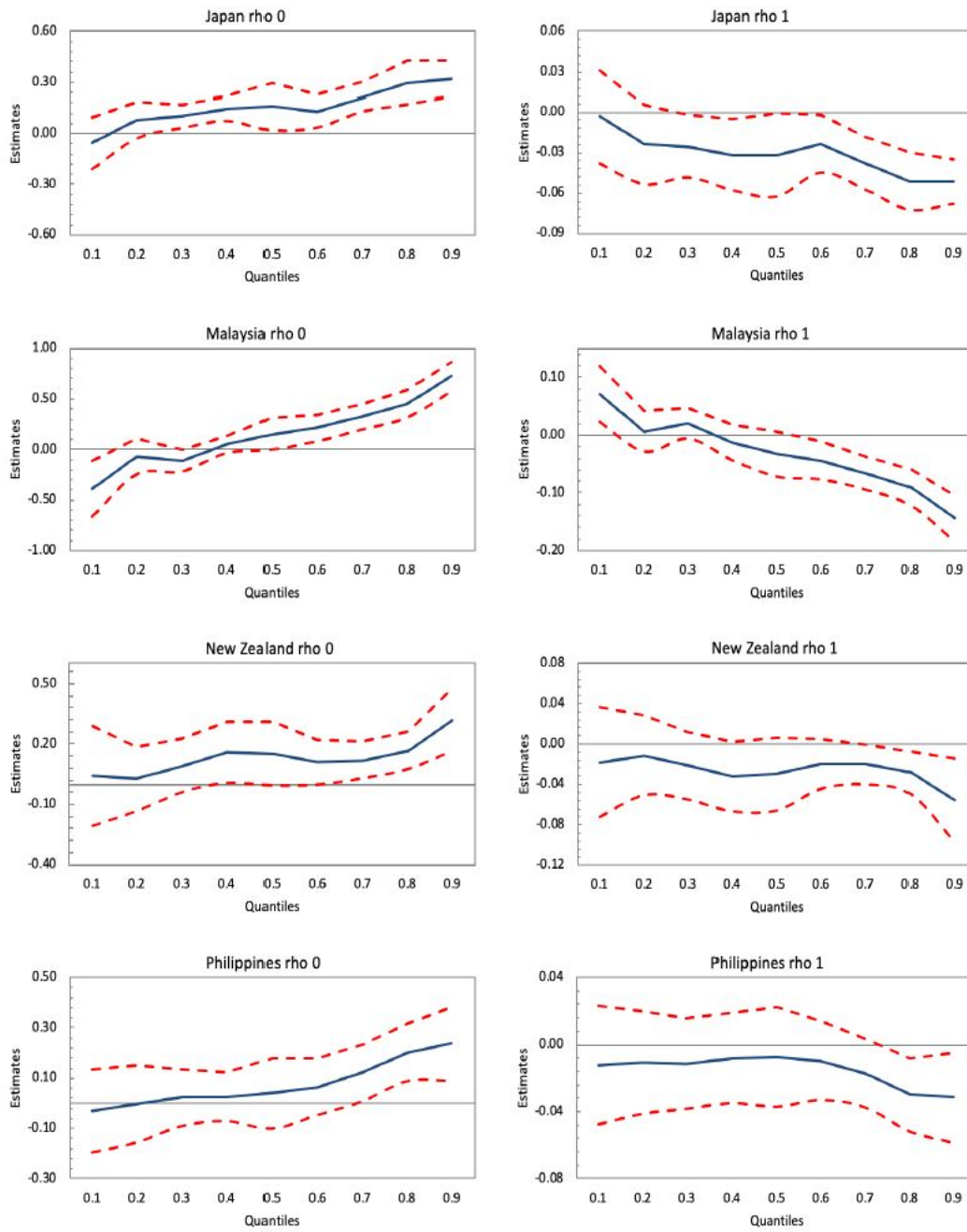


Figure 2. (Continued)

